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FETID BARITE OCCURRENCES, WESTERN BERKS COUNTY, PENNSYLVANIA

Samuel W. Berkheiser, Jr.

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Pennsylvania Geological Survey

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PREFACE

This study is one of a series of reconnaissance investigations of industrial-mineral resources in the Commonwealth. It provides geologic information on an area containing barite occurrences.

The data collected, compiled, and interpreted in this report are intended primarily to assist the suppliers and users of barite in identifying potential areas for exploration. This includes companies supplying barite to the drilling-mud, paint, glass, rubber, and barium-chemicals industries. The lithologic-float maps may also be used to provide some insight to a geologically complex area.

Most barite is used as a weighting agent in drilling for oil and gas. Barite consumption for this use has increased rapidly in recent years. If minable deposits are identified, Pennsylvania's central location could make the Commonwealth competitive as a supplier of drilling-mud additives for oil and gas exploration in the East.

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(in pocket)

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FETID BARITE OCCURRENCES, WESTERN BERKS COUNTY, PENNSYLVANIA

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Samuel W. Berkheiser, Jr.

ABSTRACT

Geologic mapping of float in an area of approximately 6 mi^2 (16 km^2) resulted in the discovery of fetid, dark-gray, nodule-like barite fragments at 11 locations in western Berks County, Pennsylvania. All showings are in a dark shale, part of the allochthonous Cambro-Ordovician Hamburg sequence. These barite occurrences, the largest of which occurs in an area of about 300 by 350 feet (90 by 110 m), have features that are associated with commercial bedded deposits elsewhere.

Belts of black shale that are large enough to contain economic barite concentrations can be mapped by float throughout most of an area about 80 miles (130 km) long in southeastern Pennsylvania. Similar occurrences have been noted by other workers at Heidelberg and Bernville, both east of the study area. A limited amount of geochemical sampling indicates that soil analysis for barium might lead to the identification of other areas that have near-surface mineralization. Samples of barite, associated rocks, soils, and stream sediments from the study area are conspicuously devoid of lead, zinc, copper, and silver; however, barite concentrates contain strontium. Organic matter is associated with the barite. Possible black bitumen coatings are present on some barite fragments, and flammable gas is liberated when crushed barite crystals are heated.

The barite probably formed early in a reducing sedimentary environment and has at least two crystal habits. The barite float examined may be the result of early replacement, as suggested by a dense core of 2-mm-sized, subrounded to subangular crystals enveloped by larger radially bladed crystals. No massive fine-grained barite with preserved sedimentary textures has been observed. The mineralization does not appear to be confined to a specific stratigraphic interval within the black shale sequences.

The clastic sequence of allochthonous sediments includes red, green, orange, and black shales and mudstones, graywackes, limestones, and cherts. Structural relationships complicate the stratigraphic succession. Mineralogic data as well as conodont color data suggest that this sequence of rocks has been subject to pressures and temperatures in the range of the zeolite-pumpellyite metamorphic facies. These conditions may have been adequate to remobilize barite.

INTRODUCTION

PURPOSE

The primary objective of this reconnaissance investigation was to identify and describe the mineral-resource potential of apparent bedded barite showings in an area of western Berks County, Pennsylvania.

The United States production of barite rose to over 2.8 million short tons, valued at $102 million, in 1981. The average price per ton f.o.b. mine site for 1981 was $35.95 (Ampian and Morse, 1982). Over 90 percent of the barite produced was used as a weighting agent in drilling muds. Nevada leads all states in production of barite, accounting for about 85 percent of the national output and 23 percent of the estimated world output. Other uses of ground barite include filler in paint, plastic, paper, and rubber; flux, oxidizer, and decolorizer in glass; and miscellaneous uses including high-density aggregate for nuclear power plant containment buildings (Morse, 1981b). Morse (1981b) estimated that the demand for barite will increase an average of about 4 percent annually through 1990.

Most of the barite mined in the United States or imported is ground at plants in Texas, Louisiana, and Nevada (Morse, 1981b). The freight rate for shipment of a high-density commodity, such as barite, from the Gulf Coast to the Mid-Atlantic Region can more than double its cost. Inasmuch as over 2,000 wells, totaling 5.5 million feet (1.7 million m), were drilled for hydrocarbons in Pennsylvania in 1980 (Harper, 1981), there is economic incentive to produce barite in Pennsylvania. If moderate success is achieved in developing the hydrocarbons in the eastern overthrust belt, offshore, or other targets, additional demand for barite in the Mid-Atlantic Region can be expected.

SCOPE

Approximately 13 field days were spent mapping and sampling about 6 mi^2 (16 km^2) in the early spring of 1982. Emphasis was placed on locating areas of barite float, identifying host lithologies, and comparing geologic features of the barite to commercially developed strata-bound barite deposits in other states.

Because of the scarcity of outcrops, limited geochemical sampling was done to determine if this method would be useful. Several composite stream-sediment, soil, and rock samples were collected from mineralized areas in an attempt to evaluate trace-element associations and mobility. Some composites of barite float were also analyzed for trace elements.

LOCATION

The study area is in western Berks County, south and east of Frystown and north and west of Wintersville, where fetid barite float occurs (Figure

6). The area is in the Great Valley section of the Valley and Ridge physiographic province of eastern Pennsylvania. Most of the land is used for 100-acre (40-ha) dairy farms.

ACKNOWLEDGEMENTS

Milt Leet, who in 1973 was a mining engineer at the Grace mine of Bethlehem Mines Corporation, thoughtfully brought the occurrence of fetid barite in Berks County to the attention of the Survey. In that same year, Jan Wise, of Myerstown, showed Leet and Robert C. Smith, II, of the Pennsylvania Geological Survey, a barite occurrence on what is now the Elvin Kurtz farm. Smith (1974) studied the mineralization, suggested the project to this author, and was an invaluable source of information and enthusiasm. Smith also provided geochemical, chemical, and mineralogical suggestions, descriptions, identifications, and interpretations. He and John H. Barnes, also of the Pennsylvania Geological Survey, reviewed the manuscript. Barnes additionally supported the project by providing X-ray fluorescence data and interpretations as well as contributing summary reports of laboratory investigations. Leslie T. Chubb, Laboratory Technician of the Survey, prepared most of the samples for analyses and provided X-ray diffraction patterns and preliminary interpretations. Arthur A. Socolow, State Geologist, supported the project and also reviewed the manuscript. Donald T. Hoff, curator of Earth Sciences at the William Penn Memorial Museum, brought sulfide mineralization in the Cambro-Ordovician Hamburg sequence to the author's attention in 1982. Mary Rose Cassa of Gulf Science and Technology Company thoughtfully provided references associating barite with bitumens.

Anita G. Harris of the U.S. Geological Survey identified conodonts in limestone samples from the study area, and determined their age and color-alteration index. Allen V. Heyl, also of the U.S. Geological Survey, provided references to similar foreign occurrences and the location of a copper occurrence near Lenhartsville.

Charles G. Stone of the Arkansas Geological Commission, Keith G. Papke of the Nevada Bureau of Mines and Geology, and Arthur W. Rose of The Pennsylvania State University critically read the manuscript and made many valuable suggestions which substantially improved the organization and content of this report. Finally, the author thanks the many landowners for their cooperation in this effort.

GENERAL GEOLOGY

The study area is located in the Great Valley section of the Valley and Ridge physiographic province (Figure 1). The Great Valley forms an approximately 10 mi (16 km) to 15 mi (24 km) wide northeast-southwest-

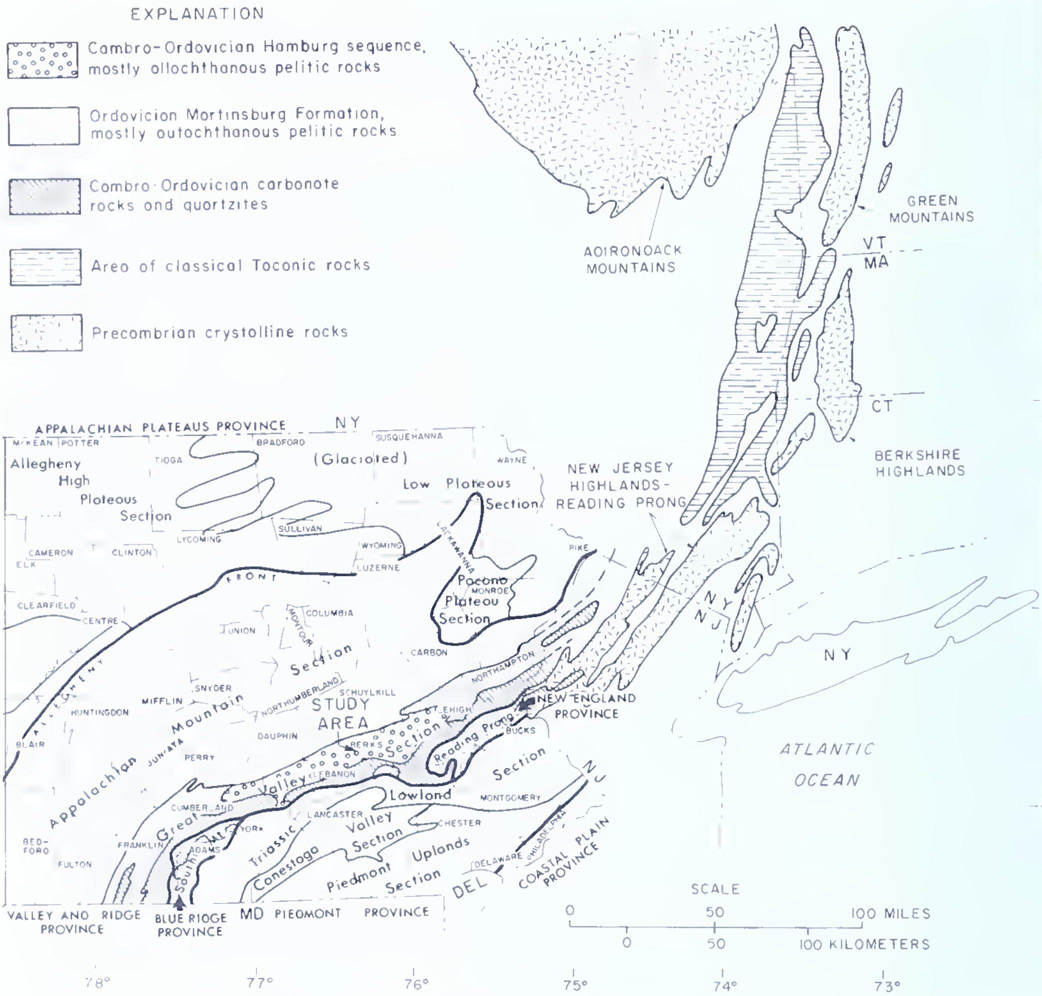

Figure 1. Map showing generalized geologic setting of the study area (modified from Root and MacLachlan, 1978).

trending belt of mostly Cambro-Ordovician clastic and carbonate rocks in southeastern Pennsylvania. Triassic-Jurassic rocks form much of the southern border of the Great Valley, as do some igneous and metamorphic rocks of the Blue Ridge province to the southwest and the Reading Prong of the New England province to the northeast. Folded Paleozoic sediments of the Appalachian Mountain section are contiguous with the northern boundary of the Great Valley. The rocks in the study area and nearby portions of the Great Valley are part of the Hamburg sequence and consist mainly of transported (allochthonous) shales and graywackes. Minor allochthonous limestones and igneous rocks are also present.

Stose and Jonas (1927) first recognized that these rocks (Hamburg sequence) are anomalous in lithology and age relative to other rocks in the region (Ordovician Martinsburg Formation). They postulated that these rocks were present in a klippe and recognized their similarity to rocks in the Ta-

conic area of New York State. Subsequently, numerous investigators (Stose, 1950; McBride, 1962; Aldrich, 1967; Drake and Epstein, 1967; Alterman, 1969; Bergström and others, 1972; Epstein and others, 1972; Platt and others, 1972; Epstein and Berry, 1973; Root and MacLachlan, 1978; Wright and Stephens, 1978; Shanmugam and Lash, 1982; and Stephens and others, 1982) have developed the concept that these rocks were transported into the area by thrust faulting and submarine gravity sliding. The evidence for this includes the recognition of the Lebanon Valley nappe structures, the apparent increasing displacement of fault-related nappe structures south of the type Taconic area, the Precambrian crystalline rocks forming the cores of nappes, multiple sequences of Alpine-type nappes, apparent gravity-slide blocks of carbonate rocks, typical Martinsburg Formation Middle Ordovician pelites occurring both southwest and northwest of the study area, and an apparent lack of Taconic (Ordovician) deformation in the Martinsburg Formation southwest of the study area. Figure 2, a generalized map of the Great Valley, and Figure 3, a generalized interpretative cross section near the study area, help to illustrate some of these concepts.

Due to multiple periods of deformation, it is difficult to determine the size and thickness of the allochthonous blocks that were transported into the basin (Root and MacLachlan, 1978). Thus, from an exploration and mining standpoint, it may be difficult to follow trends and stratigraphic markers, unless there are some large coherent bodies that have moved as single blocks. The geologic setting might be characterized as one of "raisins in the pudding." The significant question is, how big are the raisins? Thickness estimates based on 25 dip measurements and on mapped contacts of the Hamburg sequence around the study area show that it could be about 33,000 feet (10 km) thick. Contributing factors to the great thickness probably include thrusting that has repeated this section, and unrecognized isoclinal folding. True thicknesses for the allochthonous sequence cannot realistically be estimated until the structure is better defined and the stratigraphic succession is clearer. However, as presently identified, the dark shales of the allochthonous Hamburg sequence lithologies appear to extend along strike for about 80 miles (130 km).

GEOLOGY OF THE STUDY AREA

Figure 6 shows the location of the study area. Plate 1 is a reconnaissance geologic map based on scattered outcrops and mapping of float. Outcrops are limited to roadcuts, stream banks, and borrow pits. However, float (eluvium and colluvium) is relatively abundant and can be used as a general guide to bedrock lithologies in this terrain. The ideal time to observe the float, which is usually concealed by crops, is early spring and late fall, especially after plowing and heavy rains. It is estimated that float could be mapped in about 40 percent of the study area during the two-month period in which field work was done for this investigation. The other 60 percent is

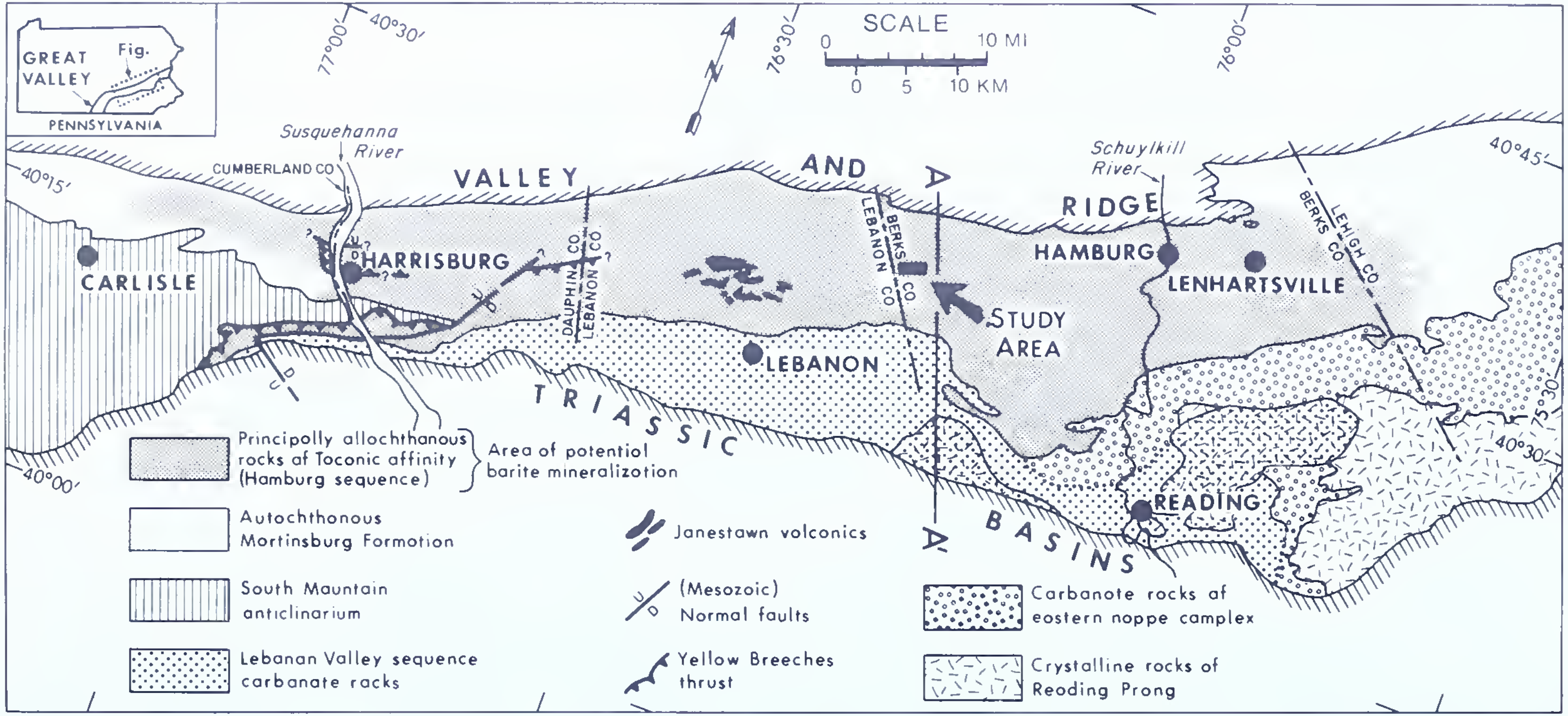

Figure 2. Generalized geologic map of the Great Valley in eastern Pennsylvania illustrating the distribution of allochthonous rocks of the Cambro-Ordovician Hamburg sequence and the area of investigation (from Root and MacLachlan, 1978). Cross section A–A′ is shown in Figure 3.

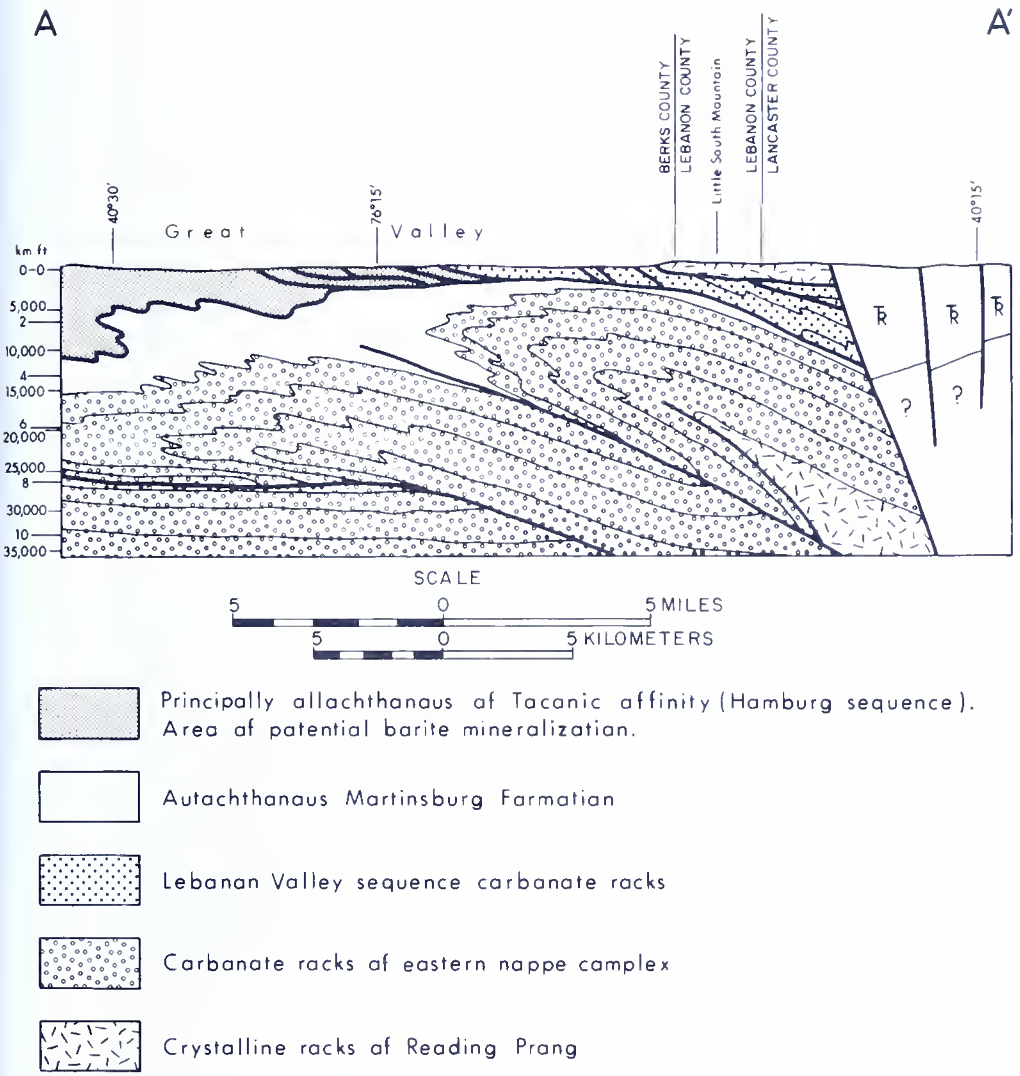

Figure 3. Generalized geologic cross section near the study area (modified from Berg and others, 1980).

largely permanent pasture and alfalfa fields. Outcrops were present where strike and dip symbols are shown on Plate 1.

The map indicates areas in which a particular float lithology predominates. The float is believed to reflect the general bedrock lithology, although other rock types could be present in small amounts within any given unit.

Significant rock types believed to underlie the area include an assemblage of red shale with some orange shale and greenish-gray shale and minor graywacke (subarkose); an assemblage of black shale containing exotic limestone blocks; a distinct assemblage of greenish-gray mudstone; and an assemblage of orange mudstone and minor shale. Chert may be present in all

of these lithologies. Rare, small igneous dikes(?) are inferred to be present in the red shale sequences.

Plate 2 shows some data from water wells drilled in and near the study area, as reported by drillers. Because of numerous uncertainties associated with these data, they were not used in the preparation of Plate 1. The data, however, suggest that there could be another dark-shale and limestone sequence immediately north of the study area. In addition, north of Wintersville there could be other similar dark-shale and limestone sequences underlying a predominantly red shale sequence. Most subsurface limestone occurrences do not appear to be correlative to nearby mapped occurrences. Descriptions of the major rock types mapped by float occurrence are given in the following discussions. The discussions of black shale, limestone, and chert are more detailed because of the association of these lithologies with commercial deposits in the United States.

Red Shale (with Lesser Orange and Minor Greenish-Gray Shales)

The red (dark-reddish-brown to grayish-red) shale is apparently the thickest lithologic unit in the study area, and, if the section is not repeated, it could exceed 5,300 feet (1,600 m). In recently cultivated fields the float has a reddish to pinkish tint, making the unit easy to recognize. An orange (grayish-orange) shale intercalated with the red shale occurs as irregular pods or lenses or as apparently thick, strata-bound beds. At several places a rapid color change from red to orange was observed along strike. Minor amounts of greenish-gray (dark-greenish-gray) shales are also found in the predominantly red shale sequence.

Graywacke

A dusky-yellow to grayish-orange, fine-grained (0.25 mm) graywacke (subarkose) is locally present in the red shale sequences. The graywacke is best exposed in two abandoned quarries, on the Moore farm about halfway between Mount Aetna and Frystown (40°26′22″N/76°18′51″W). Here, two massive, 6-ft- (2-m-) thick beds are separated by a 2.5-ft- (0.8-m-) thick grayish-orange silty shale. Randomly oriented white milky quartz veins 1/4 to 1/2 inch (0.6 to 1.3 cm) thick are common. Petrographic analysis reveals that quartz and feldspar are the major minerals present and that minor amounts of sericite and traces of rounded, green glauconite grains (tentatively confirmed by refractive index and X-ray diffraction by R. C. Smith, II, personal communication, 1982) and some black opaque minerals are also present.

Similar graywacke float is abundant on the Huber farm (40°27′04″N/76°18′30″W) in an area of gray mudstone associated with the northern black shale belt. The Huber occurrence contains abundant glau-

conite. X-ray diffraction analysis of float samples from the Huber farm suggests major quartz, minor chlorite and feldspar (microcline), and trace mica (glauconite) and smectite(?).

Black Shale

The black (medium-dark-gray to grayish-black) shale sequences are perhaps the most difficult to distinguish in the field as most of the float is weathered on the outside to a grayish-orange to dark-yellowish-orange color. By breaking the float fragments, the intrinsic color can be determined. Most of the field time was spent delineating areas underlain by black shale, because most of the barite is believed to be in this unit. Most limestone is also believed to be present in the black shale sequences.

Two east-west-trending black shale belts separated by a thick sequence of red shale group lithologies were delineated (Plate 1). The southern belt is apparently larger and more continuous and also contains the most barite float. Thickness estimates of the southern black shale belt range from 1,300 feet (400 m) in the west to an aggregate of 1,900 feet (580 m) immediately east of Pa. Route 501 (which includes a 600-foot- (180-m-) and a 700-foot- (210-m-) thick sequence of black shale separated by 600 feet (180 m) of orange shale and claystone), and to about 2,000 feet (600 m) further east. The northern black shale belt apparently ranges from a few feet to about 950 feet (290 m) in thickness. The thickest portion probably contains a middle sequence of greenish-gray claystone.

Pyrite is probably relatively abundant in these sequences, as it is in most black shales. Staining and occasional limonite pseudomorphs after pyrite, however, are all that is generally observed. Rare graptolites are found in similar lithologies near Strausstown (J. D. Inners, personal communication, 1982). X-ray diffraction scans of six black shale samples indicate that they are generally similar and are typical shales. Quartz is the predominant mineral present. All contain significant amounts of chlorite and mica and minor to trace amounts of feldspar (Table 1). The presence of more microcline than albite might weakly suggest a volcanic source for some sediments.

The presence of trace amounts of apatite is confirmed by X-ray fluorescence tests for phosphorus, which shows a maximum concentration of about 1 percent P_2O_5 in sample B-41-82 (Burkholder farm). It was not possible to distinguish between fluorapatite and carbonate-fluorapatite by X-ray diffraction methods. The apatite may occur in the conodonts. Table 2 shows some P_2O_5 estimates in black shales and other rocks as determined by X-ray fluorescence.

Limestone

Limestone, black chert, and nodule-like barite fragments are intercalated with black shale. Limestone generally occurs as restricted concentrations of

Table 1. *Summary of X-ray Diffraction Results for Composite Black Shale Samples*

Sample no.	Location	Major	Minor	Trace
B-35-82	Bohn (40°25′45″N/76°17′12″W)	Quartz	Chlorite Mica Smectite Feldspar (microcline)	Feldspar (albite) Calcite(?) Possible apatite[1]
B-41-82	Burkholder (40°26′54″N/76°17′02″W)	Quartz	Mica Feldspar (albite) Feldspar (microcline) (to trace)	Chlorite Smectite(?) Apatite[1]
B-42-82	Gibble (40°26′09″N/76°19′33″W)	Quartz	Chlorite Mica Feldspar (microcline)	Feldspar (albite) Calcite(?) Pyrite(?)
B-46-82	Kurtz barn (40°26′05″N/76°18′54″W)	Quartz Mica	Chlorite Smectite Feldspar (microcline) (to trace)	Feldspar (albite) Pyrite(?) Apatite[1]
B-47-82	Kurtz main show (40°26′06″N/76°19′01″W)	Quartz	Mica Feldspar (microcline) Chlorite (to trace)	Feldspar (albite) Calcite Pyrite(?)
B-51-82	Kurtz-Landis (40°26′04″N/76°18′29″W)	Quartz	Chlorite Mica Feldspar (microcline) Feldspar (albite) (to trace)	Pyrite(?)

[1] Apatite was identified by X-ray diffraction and its presence was confirmed by X-ray fluorescence tests for phosphates. The data did not permit deter-

Table 2. *X-ray Fluorescence Estimates of P_2O_5 in Composite Black Shales and Other Rocks*

Sample no.	Description	Location	XRD[1] apatite	Percent P_2O_5
B-35-82	Black shale	Bohn 40°25′45″N/76°17′12″W	Trace(?)	0.2
B-41-82	Black shale	Burkholder 40°26′54″N/76°17′02″W	Trace(?)	1.0
B-46-82	Black shale	Kurtz barn 40°26′05″N/76°18′54″W	Trace(?)	.6
[2]B-16-82	Dark fine-grained pyritic material	Miller 40°27′07″N/76°17′51″W	Major to minor	5.9
[3]B-54-82	Weathered sedimentary(?) float	Burkholder 40°26′54″N/76°17′02″W	Minor	2.7

[1] X-ray diffraction.

[2] B-16-82 is a very fine grained, dark pyritic rock containing 0.03 mm pyrite spheres and silicified fossil fragments (trilobites?); quartz, chlorite, and an apatite-group mineral are the other mineral constituents.

[3] B-54-82 is a weathered siltstone containing major quartz; minor apatite, albite feldspar, and mica; and trace microcline feldspar, chlorite, and possible smectite.

tabloid float. Two pairs of small limestone outcrops occur within the study area. The southernmost group is on the Bohn farm in the creek bed of a northwest-flowing tributary to Little Swatara Creek about 0.9 mile (1.5 km) northeast of Mount Aetna (40°25′46″N/76°17′10″W and 40°25′49″N/76°17′18″W, respectively). The second group is in the bed of Little Swatara Creek on the Burkholder farm about 1.9 miles (3.1 km) south of Bethel (40°26′52″N/76°17′08″W and 40°26′48″N/76°17′07″W, respectively). Both occurrences are similar in that they appear to be two separate limestone units about 100 feet (30 m) thick separated by about 100 feet (30 m) of black shale, and they appear to have a podlike form. In both cases the two limestone units differ in strike and dip. Barite float is present near both occurrences. Most of the limestone is a thin-bedded, flaggy, medium-dark-gray to grayish-black, very fine grained lime mudstone[1] which has a characteristic conchoidal fracture surface. The flaggy limestone generally has partings containing about a millimeter or less of black shale. Because of its smooth and evenly bedded nature and black color, many farmers and water-well drillers refer to it as slate. Occasionally, undulatory surfaces and lensoidal bedding can be observed. Locally, minor beds of carbonate wackestone,[2] packstone,[3] and quartzose packstone as well as intraformational flat-pebble conglomerate are present within the limestone. Limestone pebbles and clasts surrounded by a carbonate mudstone matrix were observed in a piece of float on the outcrop on the Burkholder farm. Clear, coarsely crystalline calcite veins up to 3/8 inch (1 cm) thick, occurring perpendicular to bedding, are also locally common here.

A common characteristic of most of these limestones, revealed in thin section, is a pellet framework with minor silt-sized, subangular to subrounded quartz grains (Figure 4). Differing packing densities and apparent size of the individual pellets alter the megascopic textures, which range from a very fine grained and tightly packed pellet mudstone to a partially crystalline, more coarsely grained pellet mudstone and wackestone. Rare oolith ghosts are recognizable in sample B-31-82 (Bohn farm). Microstylolites are common in most of these limestones and are regularly spaced about 5 mm apart in sample B-37-82 (Burkholder farm). Abundant anhedral, disseminated pyrite is common in all limestones, as is a coarsely crystalline twinned-calcite fracture filling.

Limestone float and outcrop were observed only in black shale units, with one possible exception on the Lloyd Kurtz farm, about 1 mile (1.6 km) northwest of Mount Aetna (40°25′51″N/76°18′21″W), near the apparent contact with black shale. Here limestone may crop out in brownish-gray to

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[1] A lime mudstone is a limestone that has a mud-supported texture and less than 10 percent carbonate grains (Dunham, 1962).

[2] A wackestone is a limestone that has a mud-supported texture and greater than 10 percent carbonate grains (Dunham, 1962).

[3] A packstone is a limestone that has a carbonate-grain-supported texture containing mud.

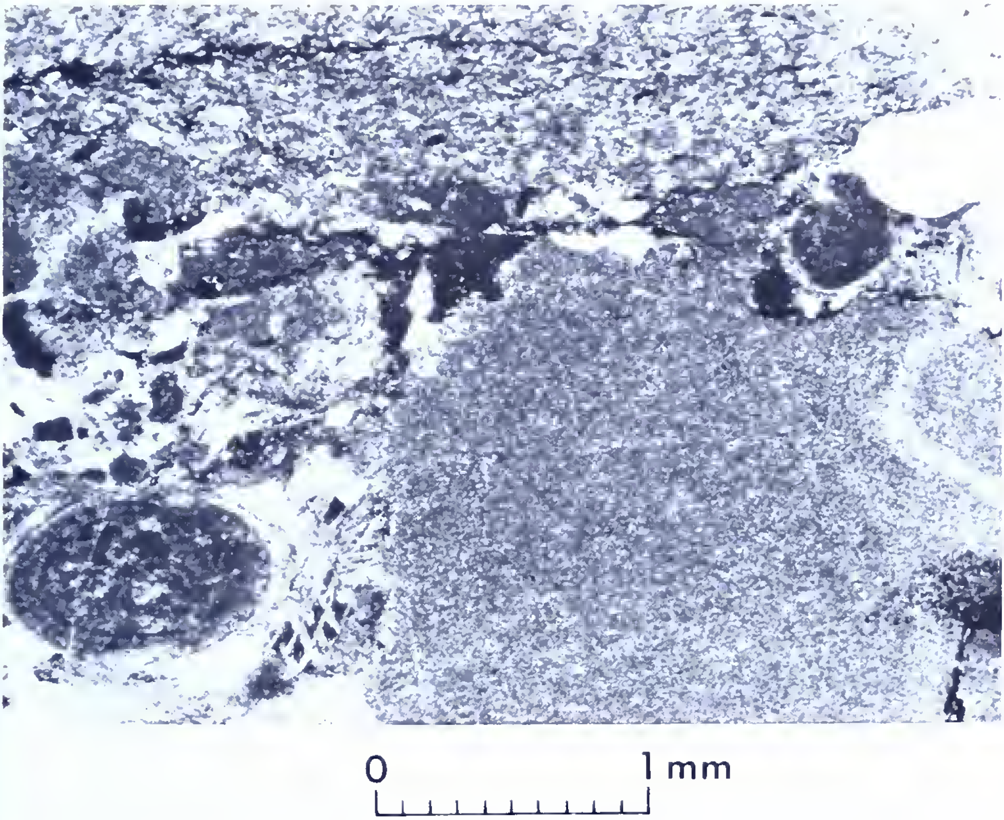


Figure 4. Photomicrograph (25X) of pellet limestone. Notice the ghost of a rare oolith in the lower left and the packing density of pellets in individual clasts. Sample B–31–82, Bohn farm. Crossed nicols.

greenish-gray shale and claystone. Epstein and others (1972) reported a similar limestone occurrence near Lenhartsville, about 25 miles (40 km) northeast of the study area, in green and red mudstones. However, in the Lenhartsville area the dark-colored limestone lenses are in contact with laminated medium-dark-gray shale.

Greenish-Gray Mudstone

Dark-greenish-gray to greenish-gray mudstone is abundant in the southern portion of the study area, south of the largest black shale belt. A similar mudstone is locally interbedded in the smaller, northern black shale belt. Some thin, fine-grained graywacke beds may occur within this sequence.

Orange Shale and Mudstone

A fissile to blocky, grayish-orange, dark-yellowish-orange, and light-brown mudstone occurs along the southern contact of the southern black

shale belt. This rock appears to be the same as that found in apparently thick sequences north and south of the study area, and contains beds of siltstone about 1 inch (2 to 3 cm) thick. Siltstone float is locally abundant in this unit; however, no outcrops were noted.

Chert

Brobst (1980) reported that barite is commonly interbedded with dark chert in other states. In the study area, minor chert apparently is present locally in all of the mappable sequences. Various shades of red and green chert have been observed. Black chert was observed in the black shale sequences and may be associated with the limestone. The black chert is laminated with a brown to black, translucent to opaque discontinuous material that could be residual hydrocarbons. Locally, it also has concentrations of carbonate crystals. Very fine grained mica could be present. Green chert has a more mottled appearance and contains round ghosts of fine-grained quartz up to 0.3 mm in diameter. Some silt-sized, subangular to subrounded quartz grains are also present in both specimens. Thin sections of a black chert, sample B-15-82 (40°26′05″N/76°18′16″W), and a green chert, sample B-13-82 (40°26′30″N/76°16′28″W), show similar mineralogy and texture. Both have a framework of microcrystalline quartz and, based on preserved laminations, appear to have formed by replacement. They also are characterized by abundant, very fine grained, disseminated pyrite that is predominantly anhedral.

Igneous Rocks

Rare float of a mafic fine-grained igneous rock (metadiabase?) was seen at several areas but examined only at 40°26′32″N/76°19′51″W (Plate 1). The size and shape of these rare igneous fragments suggest that they occur as thin (less than 2 inch, or 5 cm) dikes. Chlorite and quartz are the major minerals. The age of these inferred dikes is unknown.

Black Sandstone

Thin, black, quartz-rich, coarse-grained (0.5 to 1 mm) sandstone was noted on the Troutman farm (sample B-8-82, 40°25′50″N/76°19′18″W). Rounded quartz grains occur in a matrix of fine-grained angular quartz and an opaque material that may be hydrocarbon. Veils (inclusion trails) are common in the rounded quartz grains. The rock contains major quartz, minor chlorite, feldspar (albite), pyrite, and mica, and trace kaolinite(?).

STRUCTURE

The general structural setting of the study area may be described as multiple sequences of Alpine-type nappes. The scale of the nappe structures

compared to the size of the study area lends itself to identifying only parts of the structures. The studied allochthonous sequences could have been transported either by thrusting or by a gravity-induced mechanism. Thrusting would probably permit the coherent movement of large blocks of rock, and gravity-induced movement would probably result in a more chaotic fracturing and mixing of rock sequences. Evidence supporting both hypotheses is present in the study area, but the evidence is inconclusive as to which process was more important. The apparently conformable nature of the contact between the black shale and the red shale sequences, as indicated by the pattern of graywacke outcrop and float in the western part of the study area beginning about 3,000 feet (915 m) southeast of Frystown (Plate 1), suggests thrusting of large, coherent blocks. Indeed, local thin olive-gray shale sequences between the red oxidizing shale and the black reducing shale might represent a transitional zone between the two units. The south contact of the southern black shale sequence, however, can be interpreted as a slump-type structure or very low angle thrust, as suggested by the irregular contact and variable lithologies. The gravity concept is further supported by the apparently discontinuous and stratigraphically exotic limestone occurrences. The northern black shale sequence appears to have lithologic associations more characteristic of continuous deposition, although locally there are apparent abrupt changes in thickness of greenish-gray mudstone and black shale. The dominance of southerly dips (overturned?) in all of the rocks supports a thrust mechanism if axial-plane cleavage has not masked true bedding attitudes.

Imbricate-fan-type thrust faulting, oriented parallel to regional strike, would be difficult to detect in this geologic setting. Numerous faults of this type can be implied from both aerial photographs and topographic maps, but there is no supporting field evidence. Possibly the northern black shale body is a fault repetition of the southern black shale body. A series of apparently minor, high-angle, transverse faults are detectable in the field by a combination of offset ridges and lithologic change along the strike. Some of these faults in the southern black shale sequence could conceivably be extensions of similar faults in the northern sequence.

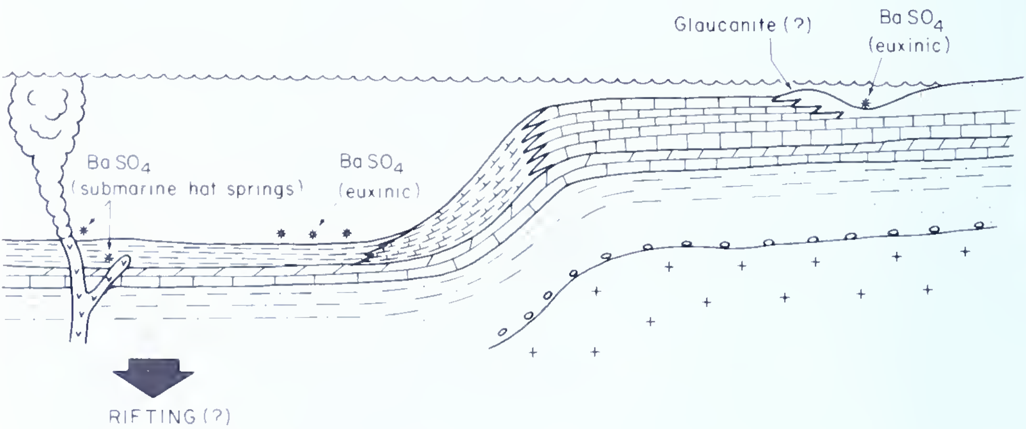
ENVIRONMENTS OF DEPOSITION

The paleogeographic setting of the study area, in eastern North America (Laurentia), in Late Cambrian through Middle Ordovician time was one of mostly shallow seas and lowlands, located in a tropical area between 20 and 30 degrees south latitude (Bambach and others, 1980).

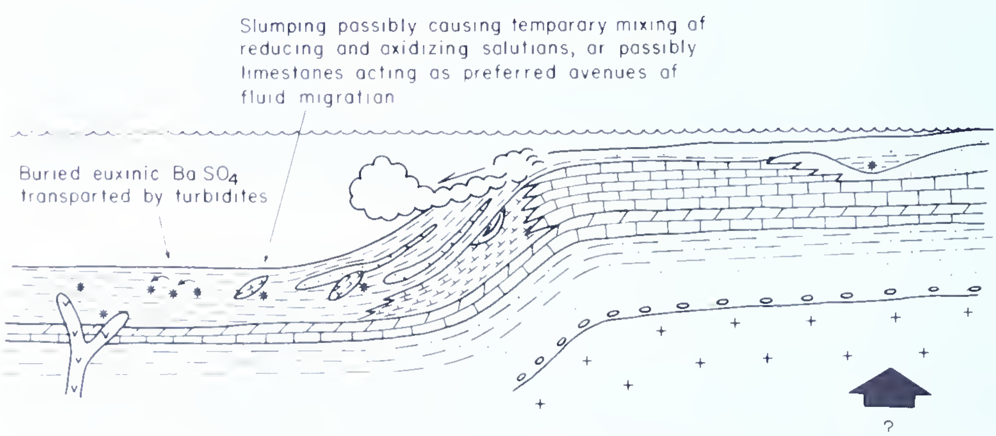
The Jonestown volcanics (Figure 2) may be remnants of an island-arc complex and a source of barium. The prehnite- and pumpellyite-bearing mineral assemblages of igneous rocks at Jonestown were interpreted by Zen (1974) as remnants of a high-pressure, low-temperature metamorphic regime formed in an active subduction zone during the Taconic orogeny.

Herting and Wright (1977) interpreted these volcanic rocks as being related to modern ocean-floor tholeiites and low-potassium island-arc tholeiites. They concluded that the depositional setting was a back-arc marginal basin. The Taconic orogeny correlates with the closing of marginal basins (Oliver, 1980; Cook and others, 1979), which probably was the mechanism that formed the multiple nappe systems.

Figure 5 is a schematic illustration of the pre-Taconic depositional and mineralogical setting of the study area. In this simplified reconstruction it is



A. Possible Late Cambrian-Early Ordovician basin-margin depositional and mineralogical setting. Possibly one of several basin-margin settings associated with microplates southeast of the North American plate. Pre-dates setting shown in (B) below.



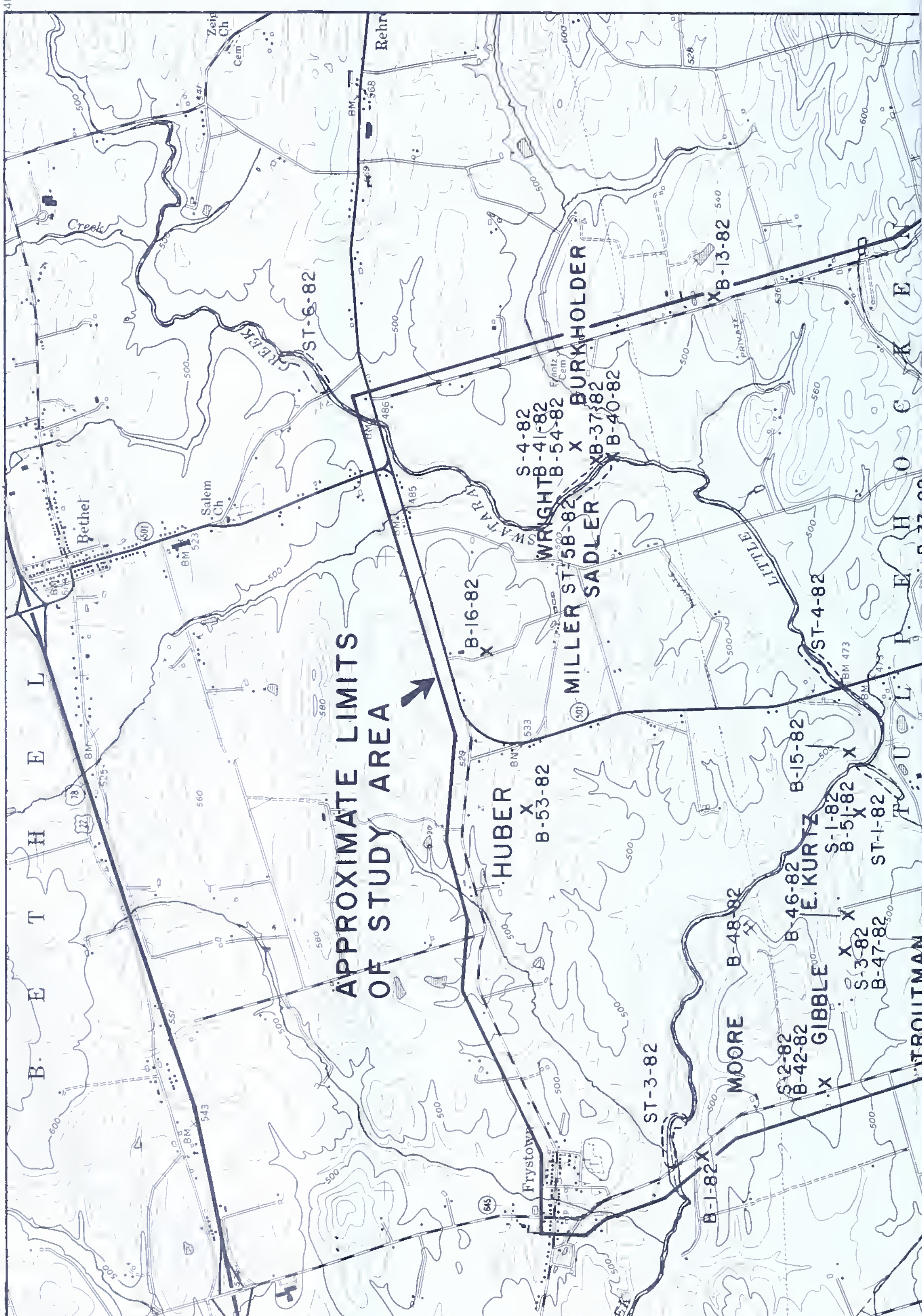
B. Same as (A) above, but showing possible depositional and mineralogical influence of continued sedimentation, turbidites, and slumped limestone prior to the main phase of the Taconic orogeny. Euxinic or hot-spring $BaSO_4$ formation could continue at the water-shale interface, but is not shown.

Figure 5. Possible pre-Taconic depositional and mineralogical settings.

assumed that all of the sediments were derived from a single basin margi which may represent a micro-continent(s) or, less likely, the Nort American plate margin. Cambrian clastic sediments (alluvial and marine were locally overlain by finer grained sediments representing deeper wate transgressive sequences such as the Harpers, Waynesboro, and Leithsvill Formations, which grade upward into thick Cambro-Ordovician shelf an platform carbonates (Figure 5A). Submarine hot springs associated wit either accretionary or subductive activity formed in the basin. The lime stones in the study area are represented in Figure 5A and 5B as slope facie transitional between the basinal shales and platform carbonates. Th ooliths and abundant pellets which are shelf-derived sediments wer probably redeposited into a deeper water basinal facies by turbidity current and gravity sliding. Reinterpretation of conclusions by Bergström an others (1972) by A. G. Harris (personal communication, 1982) suggests tha the conodonts in these limestones represent deep, cool-water assemblage associated with sediments occurring outward from the shelf edge (slope an basin facies). The general lack of fauna, and the homogeneous lime mud stone, dark color, and thin limestone interlayered regularly with thinne beds of dark shale, may represent characteristics commonly associated wit off-shelf or basinal facies as described by Wilson (1969) and Tyrrell (1969) Some limestone beds probably contain turbidite slope facies, based on th occurrence (albeit rare) of floating pebbles, conglomerates, and cross bedded quartz-wackestones and packstones. McBride (1962) and Epstei and others (1972) concluded that similar nearby exotic limestones wer formed in a shelf environment and redeposited in deeper water by slumps storm waves, and turbidity currents.

Stephens and others (1982) believed that the black shales were deposite in deep water (outward of the continental slope). The black shales coul represent a marine euxinic (stagnant, restricted, and anaerobic) environ ment, a belief that is substantiated by the lack of shell fauna and the unbur rowed and laminated nature of the shales. The apatite and smectite detecte in the black shales might be related to volcanic activity. On the other hand some of the P_2O_5 values (Table 2) might be derived from organisms. Severa marine euxinic environments in which the black shale may have formed ar illustrated in Figure 5A and 5B.

The red shales were deposited in an oxidizing environment. They coul have been deposited in various settings, such as marine, starved basin, o terrigenous subaerial. Wright and Feeley (1979) reported that the color dif ference between red shales and nearby green shales is primarily due to a dif ference in Fe_2O_3/FeO ratios and concluded that the color is a depositiona or early diagenetic feature of a red sediment. McBride (1962) interpreted th red shales to be an abyssal deposit, based on sponge spicules an radiolarians found in associated cherts. These red shales may have forme penecontemporaneously with the black shales in a basinal setting (Figure 5A and 5B).


76°15'21"
40°28'39"
APPROXIMATE LIMITS
OF STUDY AREA
BURKHOLDER
WRIGHT
SADLER
MILLER
HUBER
E. KURTZ
GIBBLE
MOORE
TROUTMAN
B-13-82
ST-6-82
S-4-82
B-41-82
B-54-82
B-37-82
B-40-82
ST-5B-82
B-16-82
B-53-82
ST-4-82
B-15-82
S-1-82
B-51-82
ST-1-82
B-46-82
B-48-82
S-3-82
B-47-82
S-2-82
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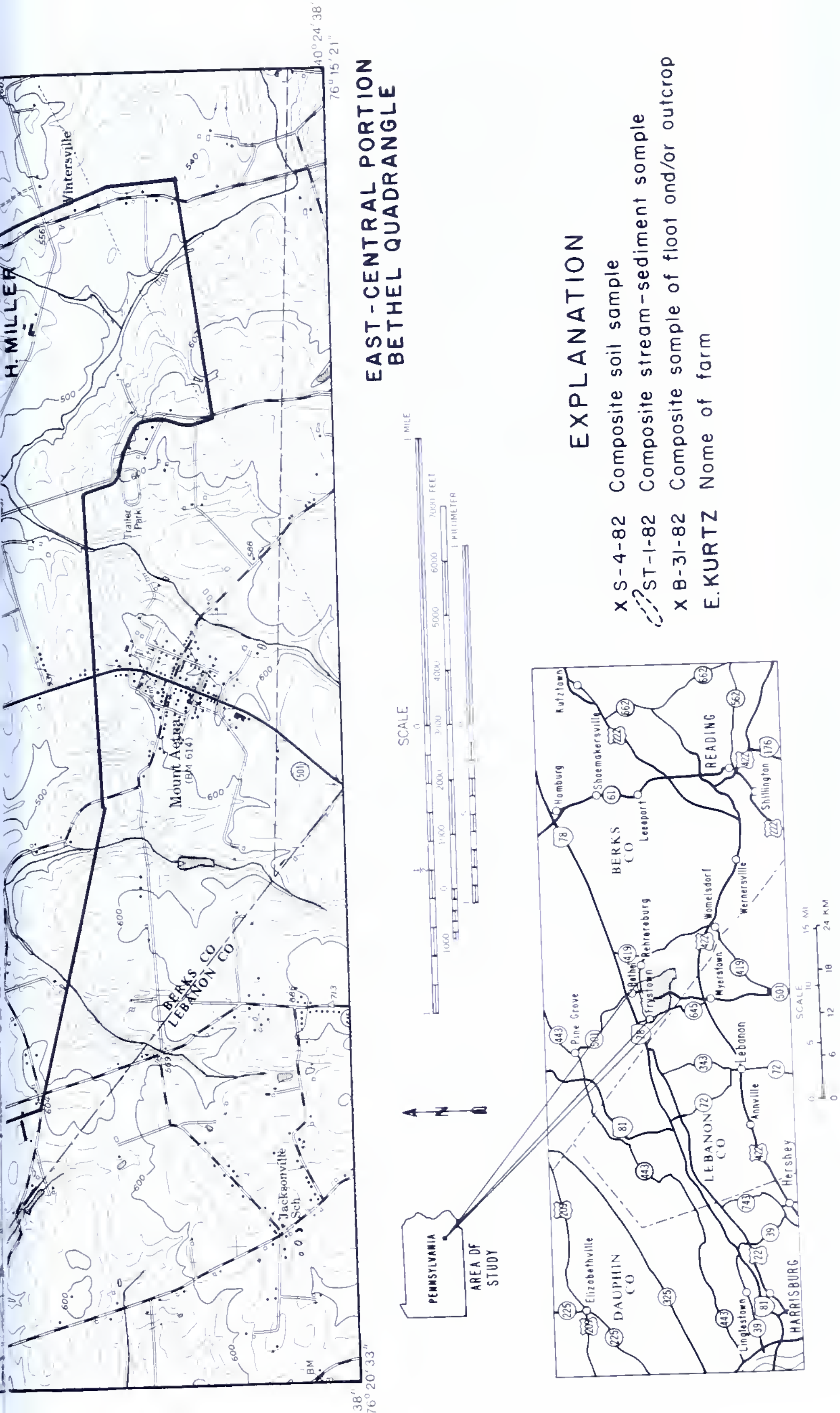


Figure 6. Location map showing the area of investigation in western Berks County, Pennsylvania.

Graywackes are commonly associated with shelf deposition, marine deposition, turbidity currents, and deep-basin deposition. The presence of glauconite favors primary deposition in shallow water during slow sedimentation (Deer and others, 1962), presumably in a shelf environment (Figure 5A). Glauconite forms under moderately reducing conditions that could be produced by the action of sulfate-reducing bacteria and decaying organisms. This environment is compatible with an expected setting for the formation of fetid, sedimentary barite. Wright and Kreps (1979), based on thin-section work, believed that both autochthonous and allochthonous graywackes located nearby were from low-grade metamorphic sources. McBride (1962) interpreted the graywackes as representing turbidite sequences transported into relatively deep water from a southeastern source area. Perhaps, then, the glauconitic graywackes represent sediments accumulated before tectonism in shallow water and are older than previously recognized. Additional insights into the depositional sequence might be obtained from a K^{40}/Ar^{40} study of glauconite.

BARITE MINERALIZATION

DISTRIBUTION

Genth (1875) noted that "a fetid barite in brownish, radiating and columnar, ferruginous masses occurs at Heidelberg." Unfortunately the 1875 reference to Heidelberg is ambiguous. "Heidelberg" could refer to any one of three townships in western Berks County (Heidelberg, North Heidelberg, and Lower Heidelberg) and one in southeastern Lebanon County (Heidelberg), or it could refer to two villages in Berks County, North Heidelberg (40°23′46″N/76°08′08″W) or Lower Heidelberg, now called Brownsville (40°21′59″N/76°04′44″W). D'Invilliers (1883) added an occurrence at Mount Aetna, which is probably one of the sites studied, and Gordon (1922) added one at Bernville, located about 10 miles (16 km) due east of Mount Aetna.

Barite mineralization was found at 11 localities within the study area (Plate 1). Eight showings are in the southern black shale belt and three are in the northern. Most barite float is nodule-like and found in areas underlain by black shale sequences. Seven significant barite showings were indicated by common float, generally occurring within areas not less than 100 by 200 feet (30 by 60 m). Four minor showings, indicating smaller areas containing only a few fragments, were noted.

Plates 3 and 4 illustrate the location, shape, and float geology of six significant mineralized areas and three minor showings. Plate 3 represents a portion of the thicker and more continuous(?) southern black shale sequence, whereas Plate 4 illustrates a portion of the thinner, northern black shale sequence. Figure 6 shows the major farm owners by name.

Barite Occurrences in the Southern Black Shale Belt

The most impressive mineralization found is in the western part of the southern black shale belt on the Elvin Kurtz farm (Figure 6; Plates 1 and 3), where significant amounts of float occur in an area about 300 by 350 feet (90 by 110 m). This occurrence was reported in the 1976 edition of *Mineral Collecting in Pennsylvania* (Geyer and others, 1976) and as a consequence has been picked over heavily. Similar but less concentrated float is present along strike in both directions, giving a total sporadically mineralized length of about 1 mile (1.6 km). Minor showings observed to the north and east of the Kurtz showings may represent a stratigraphically lower mineralized zone, or a repeated section due to undetected imbricate thrusting and/or isoclinal folding. It is difficult to determine if the larger barite showings in this area all occur in the same stratigraphic interval within the black shale, but measurements from both the northern and southern contacts suggest that there are multiple stratigraphic zones. The barite is strata-bound in the sense that it apparently occurs only in the black shale units. The limestone appears to have even less correlation with stratigraphic position than the barite except for an intermittent concentration of float near the erratic southernmost black shale contact.

Barite Occurrences in the Northern Black Shale Belt

The northern black shale sequence (Plates 1 and 4) contains three known barite showings, two of which (Sadler and Burkholder) may be significant. The southernmost black shale unit on the Burkholder farm (stratigraphically higher?) is apparently barren of mineralization, but two previously noted limestone units crop out along the creek bank.

The Burkholder showing, the most easterly in this belt (40°26′54″N/76°17′02″W), was examined under ideal conditions after the field had been plowed and washed by rain. Unfortunately, the contiguous field to the west was covered by mature alfalfa. Float of medium- to fine-grained barite occurs in an area of 200 by 100 feet (60 by 30 m), elongated along the strike of the black shale. This sequence is bounded by greenish-gray mudstones.

Barite from the Burkholder occurrence is finer grained than any of the other showings. It is characterized by medium-crystalline (average about 0.2 mm), compact aggregates of barite crystals, which locally appear indistinctly laminated and might be interpreted to suggest replacement. However, a coarser crystalline envelope is still generally present along the border (Figure 7). These envelope zones are about 5 mm in thickness, and the bladed crystals appear randomly oriented and poorly developed. Another distinguishing characteristic of the Burkholder material is the blocky nature of the individual float fragments, which may indicate a change from

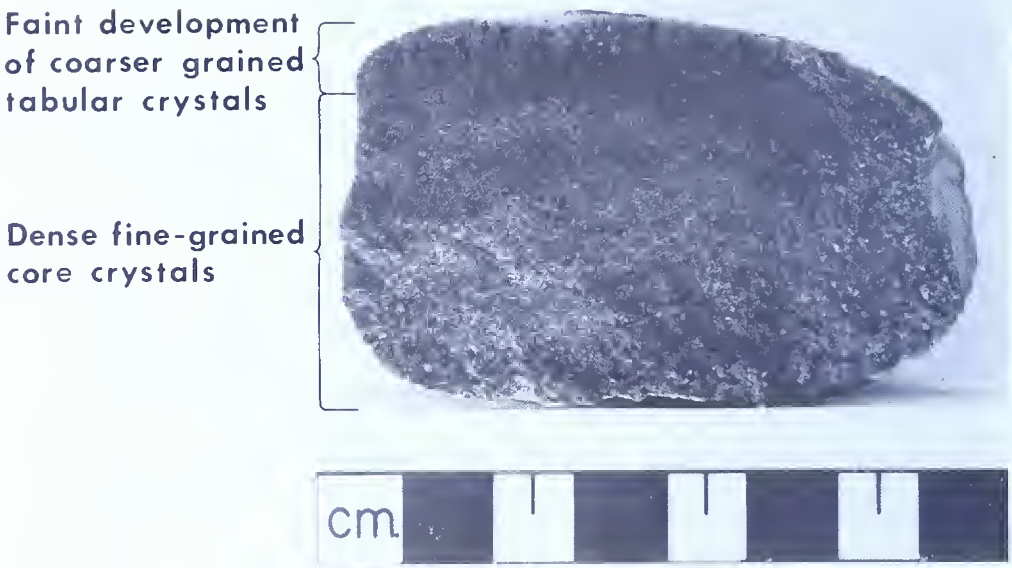


Figure 7. Finely crystalline barite from the northern black shale belt. Notice the faint development of coarser grained tabular crystals at the nodule boundary. Sample B–27–82, Burkholder farm.

nodular or lensoidal barite concretions to thinly bedded ones. The thickest fragments observed do not exceed 5 cm (2 in.) in thickness. Some faint, thin (limonitic?) laminations that weather more preferentially than the barite were noted, as were a few grains of fresh pyrite.

The conspicuously finer grained barite in the Burkholder area (Figure 7) contains a few ovoid grains of pyrite in both the outer rim structures and the core material. A black, shiny, possibly organic (bitumen? or coal?) substance was seen on some fracture surfaces as thin, rare, small blebs.

Thin sections of barite from the Burkholder area show distinct 0.1- to 0.2-mm-thick quartz envelopes around most of the subrounded to subangular, fine-grained core material (Figure 8). This replacement can also be observed in vugs and embayments within individual crystals. There also appears to be more concentrated clay-shale residue in these fragments. The finer textured core material from this showing appears more rounded than that of any of the other showings. The barite fragments from this showing also appear to be the least deformed.

The Burkholder occurrence is separated from the Sadler occurrence to the west by a fault, and the western side is believed to be downthrown (Plates 1 and 4). The Sadler occurrence (40°26′53″N/76°17′24″W) is characterized by coarsely crystalline barite fragments in an area of about 200 by 75 feet (60 by 23 m), elongated parallel to strike. Most of the barite fragments have a distinct sheared or fractured appearance. The black shale sequence, which

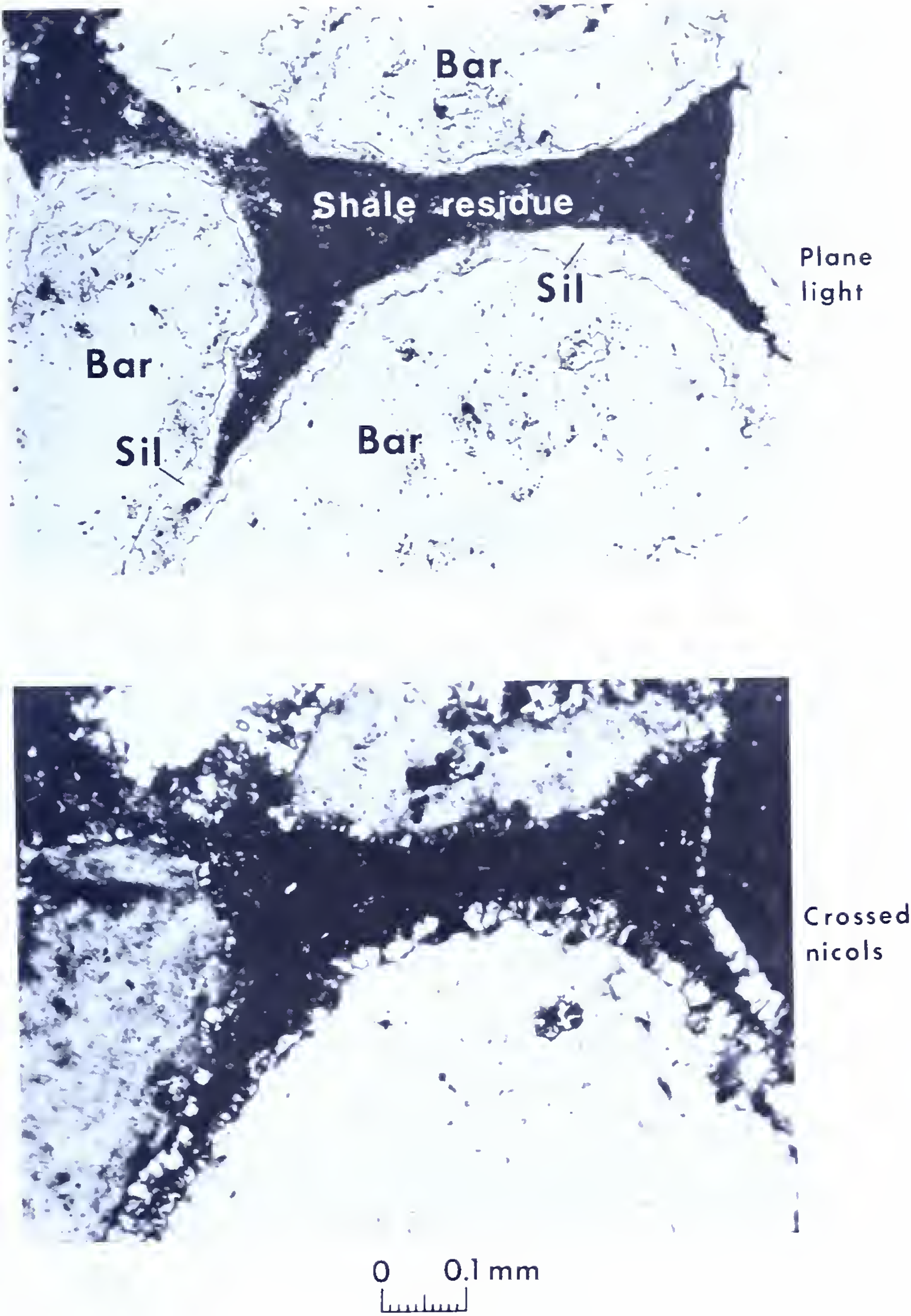


Figure 8. Photomicrographs (100X) of rounded to subrounded barite (Bar) core crystals showing silicification envelopes (Sil). Notice that silica replaces the barite crystal habit. Sample B–27–82, Burkholder farm.

apparently is thicker than at the Burkholder occurrence, may have an undetected greenish-gray mudstone sequence near the middle, as such beds were observed to the west and east.

Apparently, the Sadler and Burkholder barite occurrences are in different stratigraphic intervals within the northern black shale sequence. The Burkholder showing occurs near or at the upper contact of a lower black shale unit and the barite is fine grained and blocky, whereas the Sadler showing occurs apparently higher in the section (assuming the beds are not overturned) and is a more typical, coarse, radially bladed occurrence. The northern black shale belt appears to be engulfed by an envelope of greenish-gray mudstone.

Another distinctive feature of barite mineralization in the northern black shale sequence is the presence of red limonitic staining at the Sadler showing and the more western Huber (Plates 1 and 2) showing. This staining occurs as thin coatings on sheared surfaces and at host rock contacts.

MEGASCOPIC FEATURES

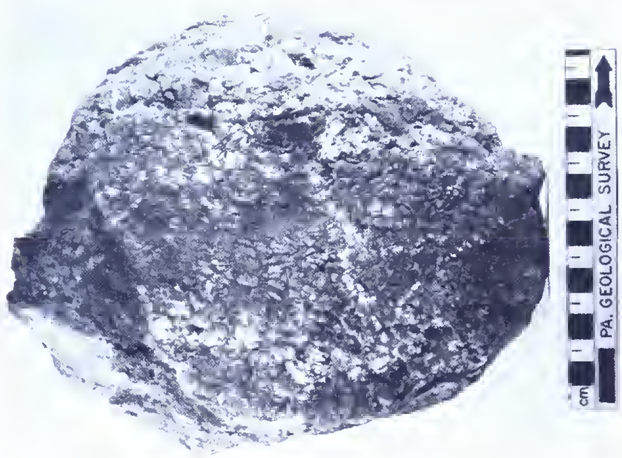
The barite generally consists of nearly pure, fist-sized, nodular or lensoidal float which is medium gray to medium dark gray and fetid. The core of the fragments is made up of dense, compact, 2-mm-sized, subrounded to subangular barite crystals which are generally surrounded by an envelope of radially bladed barite (Figure 9). Some core fragments appear to have a faint lamination with a pale-yellowish-orange to gray to grayish-black argillaceous material occurring at crystal boundaries and as occasional interstitial fillings (Figure 10). This argillaceous material has been interpreted as shale residue based on X-ray diffraction. Some of the radially bladed crystals appear deformed and some display a color zoning parallel to the *c*-axis in which the center is lighter in color than the outer part (Figure 11). Crystal cleavage surfaces often are very irregular. Most of the radially bladed crystals appear to originate from a common center. Limonitic and rarer reddish limonitic staining is present on the barite. Some nodules contain rare limonitic boxworks 1 to 2 mm across which may be pseudomorphous after pyrite.

It is difficult to estimate the true thickness of individual nodules or lenses from the fragments. Some of the nodules have borders of black shale (Figure 12). The radially bladed coarse crystal clusters that originate from a common center appear to be boundaries of the nodule or lens. Some lenses appear to have a randomly oriented bladed-crystal structure which might represent the disturbed outer remnant of radially bladed crystal growth. A thin zone of parallel-bladed crystals, perpendicular to the long axis of the lens, is also sometimes present (Figure 13). The average lens thickness is estimated to be about 5 to 7 cm (2 to 3 in.).

The presence of lighter colored crystalline barite veinlets (1 to 3 mm thick) suggests that minor remobilization of barite has taken place (Figure

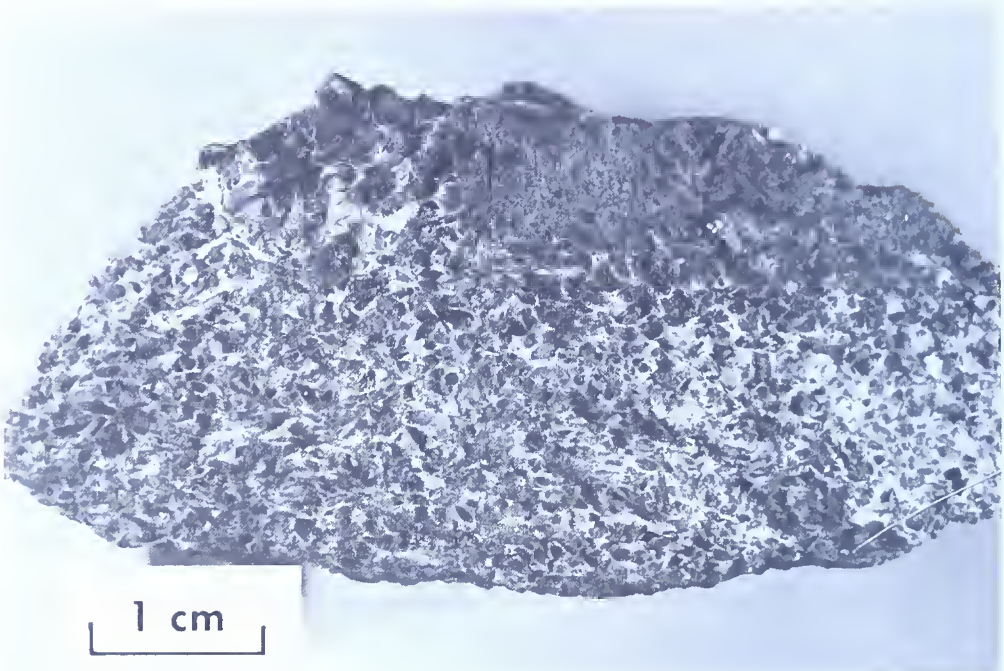
A. Fragments of barite nadules shawing the radially bladed auter rim crystals merging with the subraunded, finer crystalline, dense care crystals. Sample B–25–82, E. Kurtz farm, main shawing.

B. Fragments af barite nadules shawing variatians af the radially bladed structure. Sample B–44–82, E. Kurtz farm, barn shawing.

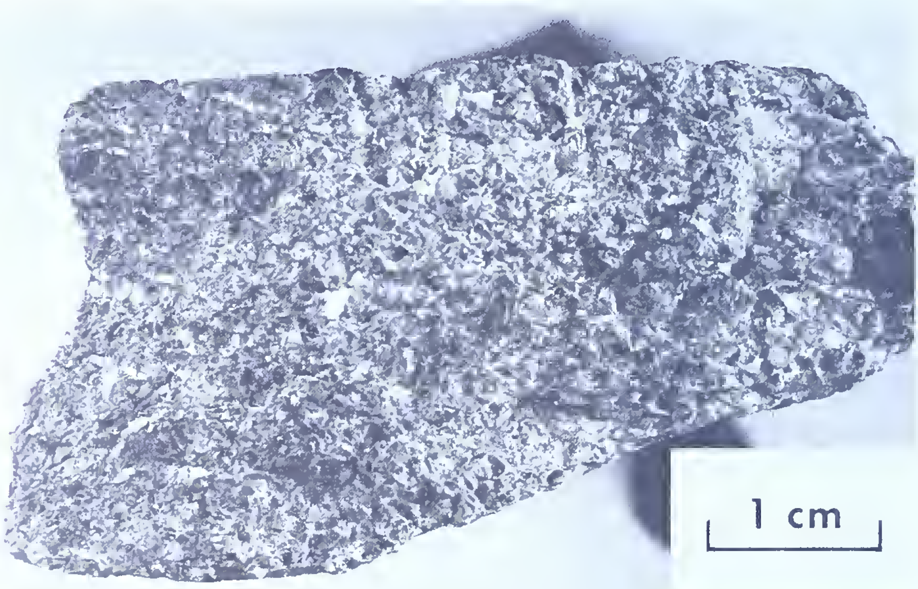


C. Rare complete nadule fram the Gibble farm (sample B–41–82). Natice the apparent large diameter af the auter bladed crystals. Plan view, abaut 8 cm (3 in.) thick.

Figure 9. Fragments of typical barite samples.



A. Indistinctly laminated, subrounded core crystals. Abundant shaly residue is present as matrix material. Sample B–25–82, E. Kurtz farm, main showing.



B. Compact and densely packed, 1- to 2-mm subrounded core crystals. Notice the lack of shaly residue as matrix compared to the sample above. Sample B–49–82, Kurtz/Landis showing.

Figure 10. Fragments of barite nodules showing variations in the core texture.

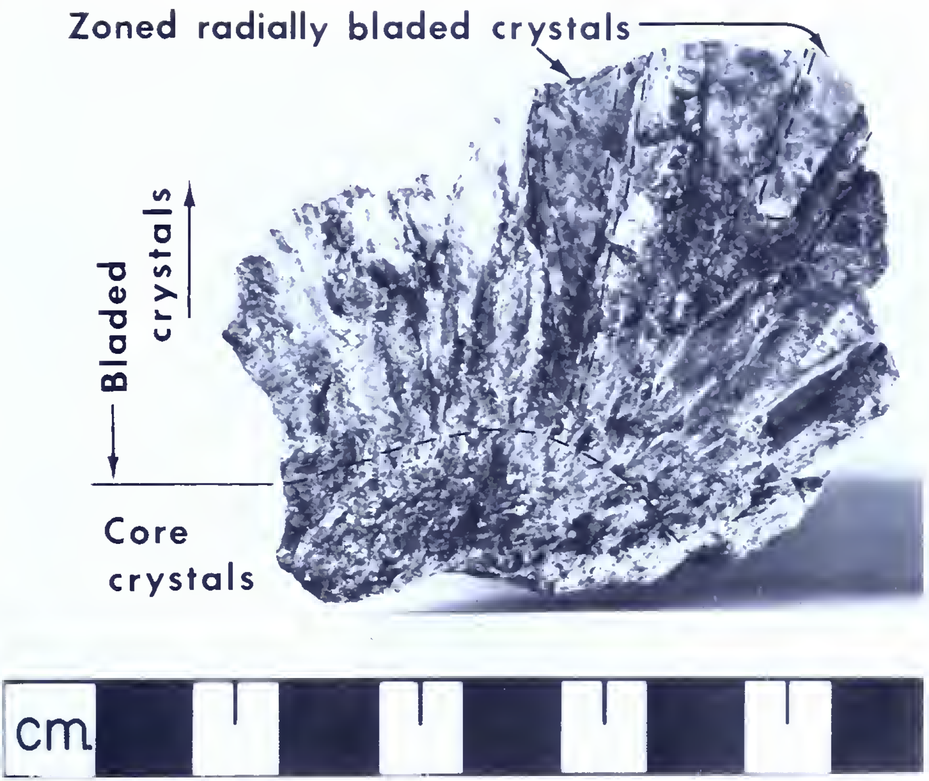


Figure 11. Fragment of a radially bladed barite nodule showing zoned tabular crystals. Some finer grained core material is visible at the base. Sample B–34–82, Bohn farm.

14). A creamy-white, drusy material occurring as fracture fillings in the nodules has been identified by X-ray diffraction as barite. Most of the barite fragments in both the north and south black shale belts have a solution-etched appearance. These are characterized by small (a few millimeters) vugs with free-standing barite crystals, the appearance of dissolution along fracture planes, and pockmarked or pitted weathered rims on nodules. Because barite is relatively inert under near-surface conditions, this evidence suggests that dissolution may be related to some past episode such as the last orogeny (Alleghanian).

MICROSCOPIC FEATURES

Thin-section examination of selected samples generally reveals undulatory extinction and granulated crystal boundaries for most barite. Longitudinal sections of the radially bladed structures have curved cleavages, some of which have a fine-grained granular texture and minor silica replacement (Figure 15). Other crystal boundaries are characterized by thin (0.1 to 0.2 mm) granulated surfaces and selvaged edges that contain minor fine-

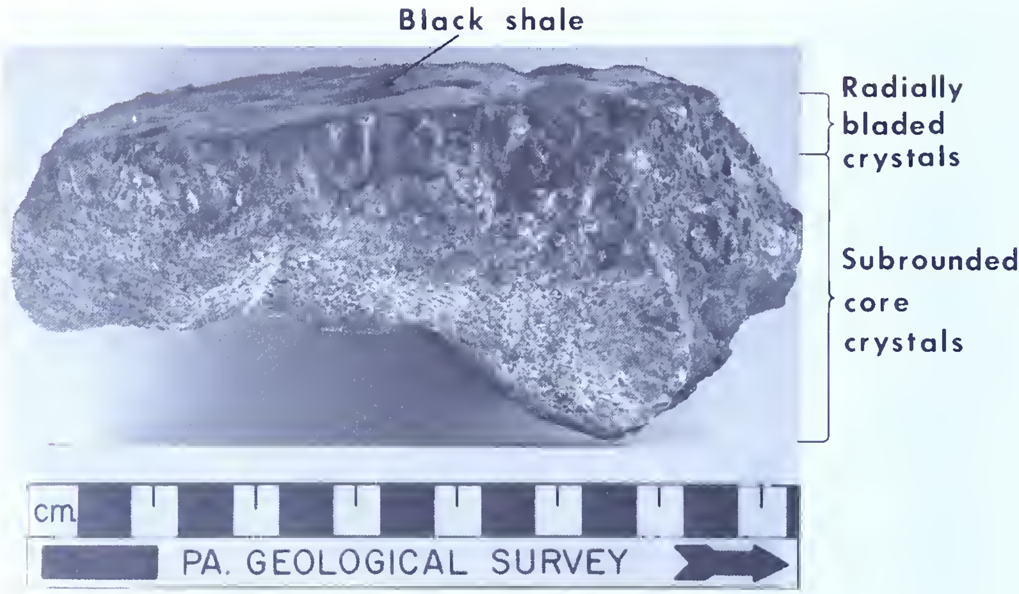


Figure 12. Fragment of a barite nodule showing various textures and crystal habits. Notice the coarser crystalline, radially bladed outer rim crystals at the top of the photograph in contact with black shale fragments. The core material is densely packed, finer grained, subrounded barite crystals. Sample B–49–82, Kurtz/Landis showing.

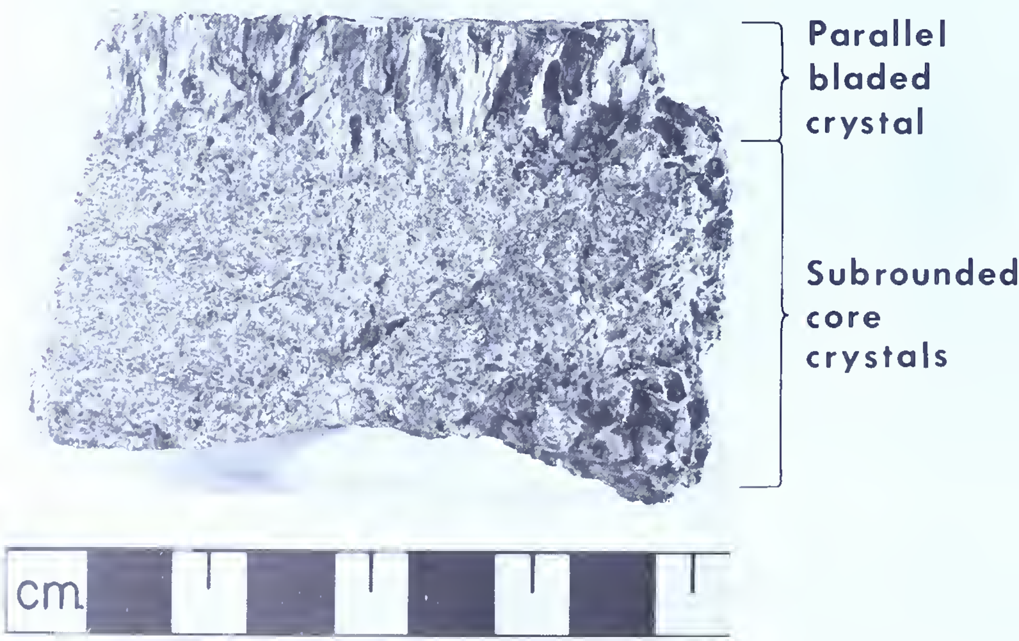


Figure 13. Fragment of a barite nodule showing coarsely crystalline, parallel-bladed crystals. Notice the more finely crystalline, subrounded core crystals. Sample B–41–82, Gibble farm.

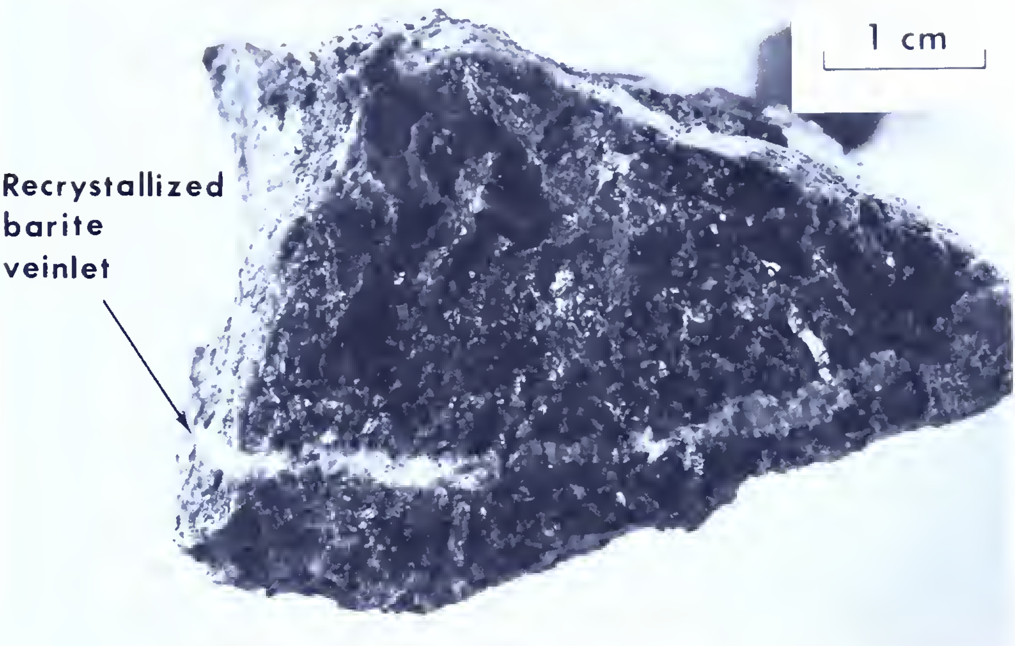


Figure 14. Fragment of a barite nodule displaying a thin, white, recrystallized barite veinlet. Sample B–19–82, Sadler farm.

grained quartz mimicking the barite crystal habit (Figure 16). Rare kinkband selvages have also been observed (Figure 17). Most quartz is of this very fine grained replacement type. However, rare coarser grained quartz is also present as veinlets that do not extend beyond the boundary of the individual barite crystals. Commonly this coarser grained quartz shows undulatory extinction. The fine-grained barite core material of these nodules generally has a subrounded appearance and may represent an episode of agitation or abrasion. Replacement silicification, the fine-grained quartz mimicking the barite crystal habit, appears more abundant in the core-type barite crystals. Both fine-grained anhedral and euhedral disseminations of pyrite occur in the barite, as well as in the interstitial shale residue. Limonitic staining is common in the shale residue. All barite crystals have dark fluid(?) inclusions, some of which form veils (trains). Studies of such materials might reveal the temperature and salinity of the barite-forming fluids.

AGE OF HOST ROCK

Studies of conodonts and graptolites indicate a Cambro-Ordovician age for the host rock in the area. Stephens and others (1982) have interpreted the Hamburg sequence to include two ages, based on graptolites found mostly in the graywackes. *Nemagraptus gracilis* is middle Ordovician in age and *Dictyonema flabelliforme* has been interpreted as lowest Ordovician in

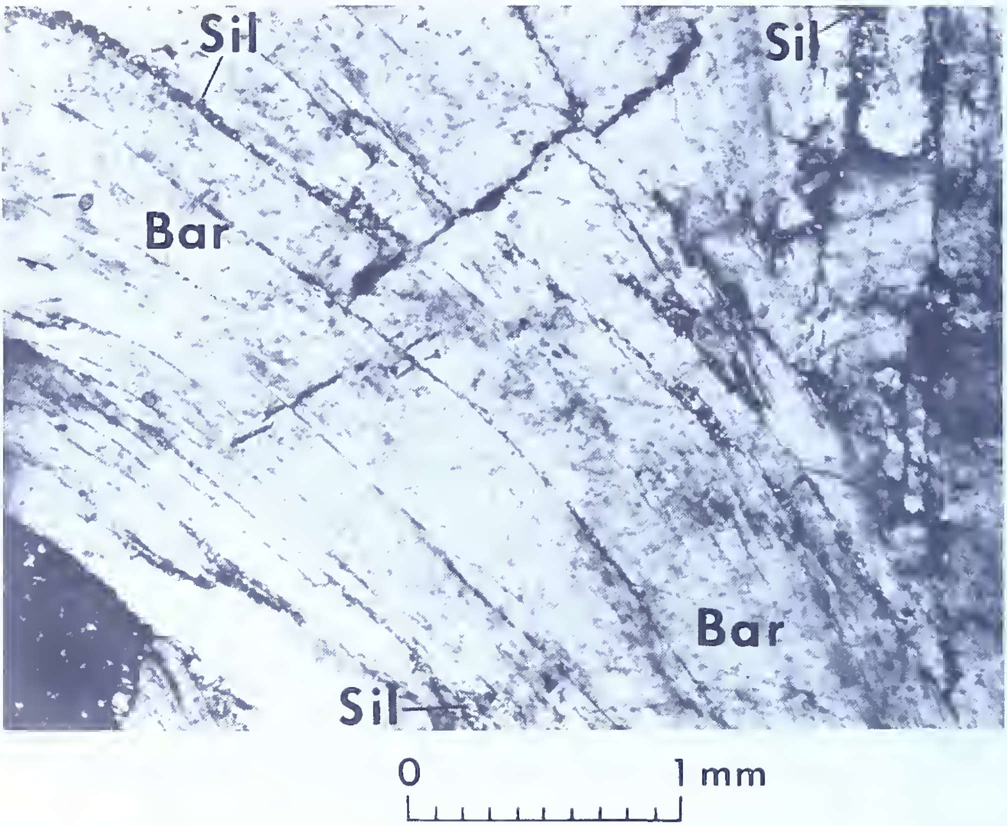


Figure 15. Photomicrograph (25X) of curved barite (Bar) cleavage and granulated cleavage surface of a bladed crystal. Silica (Sil) has replaced some of the granulated barite. Sample B–34–82, Bohn farm. Crossed nicols.

age. Limestone in the study area, occurring within the black shale sequences, has been interpreted as late Cambrian in age, based on conodont assemblages (Harris and others, 1982). Conodonts from limestone slide blocks of the Hamburg sequence further east, near Lenhartsville, are reported to be of early Ordovician age (Epstein and others, 1972). The apparent older age for the limestones in the black shale sequences can be explained by assuming that the limestone occurrences are related to slump structures, based on erratic stratigraphic position and limited strike length. Older shelf carbonates may have been placed in a younger shale basin through submarine uplift, erosion, and transport.

PARAGENESIS

Barium is one of the more abundant minor elements in crustal rocks (Rose and others, 1979). Within the perspective of this reconnaissance study, and taking into account the general lack of mineralized outcrops in the study area, a tentative genesis-paragenesis is offered.

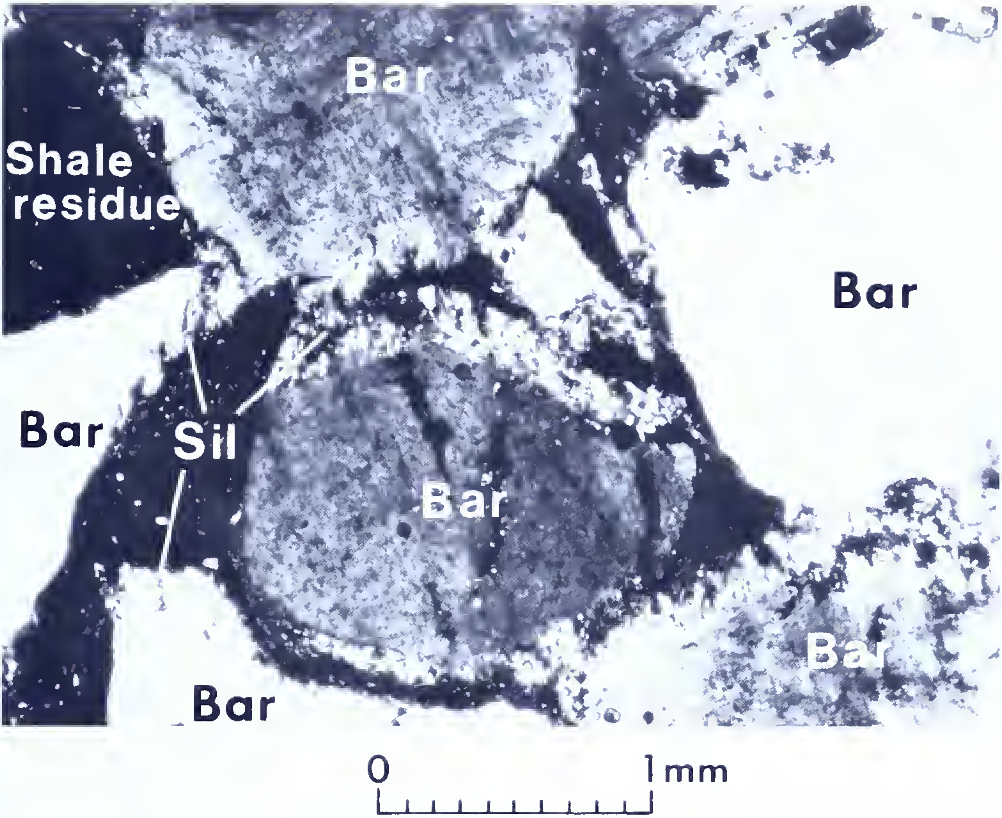


Figure 16. Photomicrograph (25X) of a selvaged boundary of a barite (Bar) crystal. Some silica (Sil) replacement is mimicking the barite habit. Sample B–49–82, Kurtz/Landis showing. Crossed nicols.

The black-shale host, the nodular character of the barite, the fetid odor and presence of organic matter in the barite, the crystal habit of the barite, and the glauconite in associated graywackes suggest that the barite formed in a sedimentary environment. Three possible settings for barite precipitation are illustrated in Figure 5: (1) two variations of an euxinic basin, (2) sea-floor hot springs, and (3) temporary solution mixing caused by slumping (limestones), or the slump blocks may have acted as avenues of preferred fluid migrations. A fourth hypothesis involving transported barite is also illustrated in Figure 5B. Because Figure 5B represents successive events that occurred later than the events of Figure 5A, most of the barite accumulation in Figure 5B is simplistically illustrated as buried. However, barite formation may have been relatively continuous throughout this time for most settings.

Barium is moderately mobile in a reducing environment (Rose and others, 1979). The precipitation of $BaSO_4$ most likely occurs at the interface of reducing and oxidizing waters. Perhaps sulfate-depleted water (reduced by bacteria) containing barium, occurring as either pore fluids or stagnant

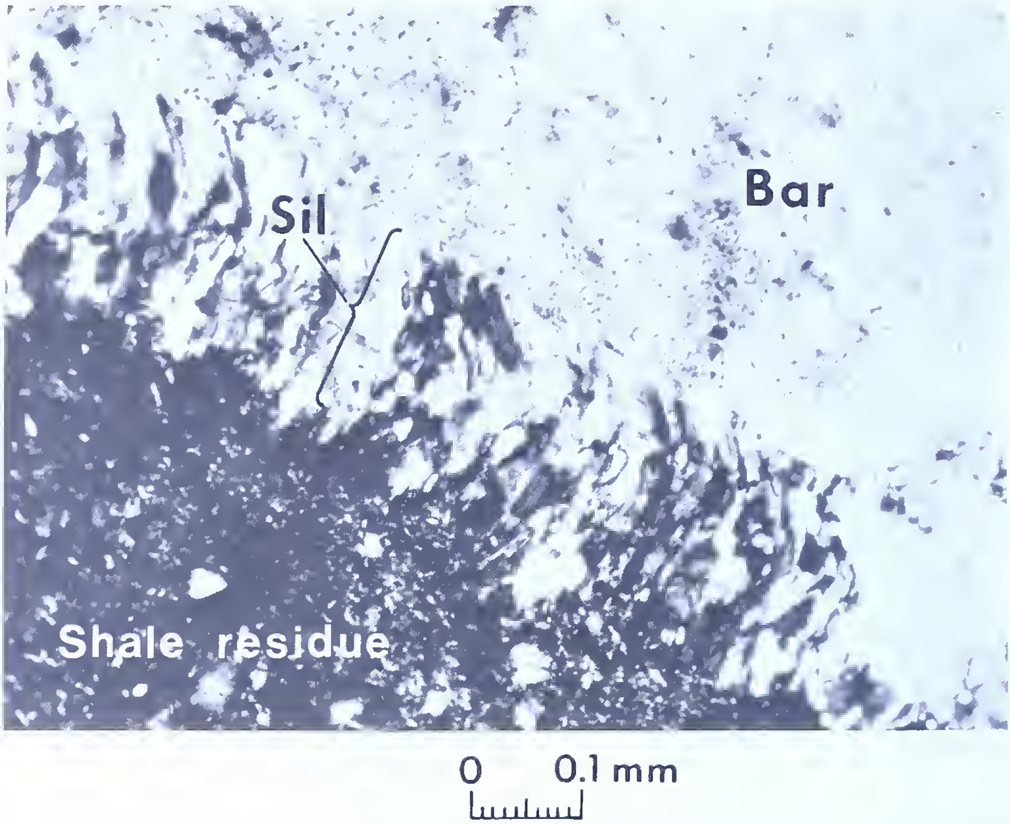


Figure 17. Photomicrograph (100X) of a kink-band selvaged boundary (Sil) of a barite crystal (Bar). Sample B–49–82, Kurtz/Landis showing. Crossed nicols.

waters below organically productive surface waters, mixes with a sulfate-bearing fluid (normal seawater) or oxidized H_2S on the sea floor and forms $BaSO_4$. If a reduced barium pore fluid emerged into anoxic water, as in a stagnant basin, the barium probably would not precipitate until encountering normal SO_4-bearing seawater (A. W. Rose, personal communication, 1983).

A hydrothermal origin such as submarine hot springs, in which the barium and heat are derived from a magma, is another obvious possibility. Rose (personal communication, 1983), however, believes that it is more likely that a magma merely provided heat for already existing pore fluids within the sediments, which would accelerate precipitation.

At least three distinct phases of barite crystallization have been observed. The core of most nodules is finer textured than the outer bladed part. These finer grained and characteristically subrounded core crystals may represent a period of fast crystal growth. They could represent a very early replacement of subrounded calcite(?) in the black shale or, less likely, a sea-floor precipitate. The outer radially bladed crystals probably represent a later pe-

riod of slower, more stable crystal growth. Temperature, sulfate concentrations, and barium concentrations could affect growth rates. Fluid-inclusion studies of both crystal habits might provide some insight into this process. The third episode of barite crystallization is limited to minor remobilization, possibly during the Alleghanian orogeny. The interstitial shaly residues in the barite nodules were probably trapped and concentrated during the barite crystal growth and concentrated again during the silicification episode(s).

Most of the barite nodules show evidence of deformation, such as a sheared appearance, selvaged edges, kink-banded selvages, and granulated crystal boundaries. Irregular barite cleavage surfaces are common, as are undulose extinctions. These phenomena are probably the result of deformation during the Taconic orogeny.

Two types of pyrite are present and may have formed separately. The very fine grained euhedral disseminations in barite could represent an early formation, whereas the generally larger anhedral disseminations in both the matrix and barite crystals might be a much later episode. If the initial pore fluids contained H_2S and iron was present in the sediment, the H_2S might be consumed to form pyrite (Rose, personal communication, 1983). Thin envelopes of quartz appear to surround some of the anhedral pyrite crystals.

Two phases of silicification may be present. One is an early filling of fractures by coarsely crystalline quartz; the crystals generally are oriented perpendicular to the long axis of the barite crystals. Each of these veinlets appears to be confined to one barite crystal. The second and more abundant type of silicification is a fine-grained, selective replacement of barite along bent cleavages and deformed crystal boundaries. Some quartz envelopes, about 0.1 to 0.2 mm in thickness, are common in the finer grained barite cores. The selvaged edges and rare kink-band selvages of the barite crystals contain quartz mimicking the barite habit. This could be interpreted as a late (post-Taconic) silica replacement phenomenon. Both forms of quartz also have some undulose extinctions. Whether the deformation of the quartz is related to the Taconic or Alleghanian episode of tectonism is unknown. The rare, coarser grained fracture fillings may be a very early silicification event.

Temperatures were apparently relatively moderate in the study area during episodes of tectonism, as indicated by the color-alteration index of conodonts. Harris and others (1982) estimated that the limestone host rock reached at least 180° to 220°C, indicated by color-alteration indexes (CAI) of 4 to 4-1/2. Work on the Jonestown volcanics further west supports a low-temperature metamorphic facies, but the level of pressure remains questionable (Moseley, 1956; Hollis, 1973; Zen, 1974).

A flammable gas is produced by heating crushed fragments of barite in a test tube. Crushed crystals lose their dark-gray color (due to inclusions?) and decrepitate into friable, very fine grained plates after heating. Most of

the barite contains abundant dark inclusions in thin sections. Connan (1979) noted bitumens associated with lead-zinc-barium ore deposits in England, Sweden, western Canada, and France. He postulated that bacterial degradation of bitumens is related to hydrocarbon-oxidizing and sulfate-reducing bacteria. The sulfate-reducing bacteria generate the H_2S required for precipitation of metallic sulfides which, other than pyrite, have not been observed in this study. He concluded that the lower maturation level of these bitumens supports a low-temperature genesis, and that they probably formed by the mixing of metal- (lead-zinc-barium), hydrocarbon- (crude oil), and sulfur-carrying fluids.

There is a conspicuous absence of associated metallic materials in the vicinity of the study area, except for iron sulfides, minor copper blooms to the east near Lenhartsville (A. V. Heyl, personal communication, 1982), and a trace copper showing in a borrow pit west of Jalappa. The latter consists of trace amounts of chalcopyrite, bornite, chalcocite, chrysocolla, and calcite disseminated in very thin (up to 5 mm) quartz veins that cut red shale and silty brown dolomite (D. T. Hoff, personal communication, 1982). Trace showings such as this are ubiquitous throughout the Paleozoic in Pennsylvania. Stream-sediment analyses by Rose and Keith (1971) and Keith and others (1967) covering southeastern Pennsylvania show only a copper anomaly southwest of the study area in Lebanon County.

Miller and others (1977) suggest that the lack of sulfide mineralization associated with high-grade barite ores (70 to 95 percent $BaSO_4$) can be attributed to a unique source of barium as well as an anoxic environment of deposition. Rose (personal communication, 1983) noted that literature about oil-field brines indicates that barium-rich pore fluids are not uncommon, but that lead-zinc-copper-bearing fluids are rare.

The apparent stratigraphic variation between the separate barite showings within the black shale sequences poses some problems with respect to barite formation. One possible explanation is that there actually is little or no stratigraphic variation and that structure and poor outcrops mask the true bed-bound nature of these showings. Conditions for minor sedimentary barite crystallization or early replacement would only have had to exist for a relatively short time period in a restricted basinal setting (Figure 5A). Conversely, perhaps favorable chemical conditions existed throughout the deposition of the black shale in a reducing environment and growth was limited by the available barium and preferred avenues of fluid migration, which theoretically could provide economic concentrations. Another possibility requires that the oxidation-reduction interface, where crystallization occurred, fluctuated through the depositional and early diagenetic cycle, producing sporadic local concentrations. A hypothesis also worthy of note is the possible allochthonous nature of the barite itself in the black shale. The Berks County showings appear similar to detrital barites reported by Reimer (1978) in southern Africa. He described deposits formed by rework-

ing of semiconsolidated clays containing barite concretions (Figure 5B). His descriptions are strikingly similar to the Berks County occurrences and include black to dark-gray to red-brown barite, traces of H_2S (fetid odor?), fine, subrounded, tabular grains, frequent aggregates of upward-diverging acicular barite, and a shale host.

EXPLORATION GEOCHEMISTRY

Composite samples of barite, stream sediment, soil, float, and bedrock were analyzed for selected trace elements in an attempt to find a usable reconnaissance exploration tool. Semiquantitative estimates of barium were made using wavelength-dispersive X-ray fluorescence. A W tube at 50kV, 45mA, and LiF (200) analyzing crystal were used to obtain the $BaK\alpha_{1,2}$ peak area. Table 3 lists the sample type, location, and results of analysis for these samples.

Stream-Sediment Samples

The samples of sediments were obtained from Little Swatara Creek and its tributaries in the study area. Several of these samples, such as ST-1-82 and ST-5B-82, were near known mineralization. No significant amounts of barium were detected for any of the five samples analyzed. All were estimated to contain less than 100 ppm (Table 3). Mobile barium cations would not be expected in this environment.

Soil Samples

The soil samples were obtained from four areas of known mineralization. All of the samples had barium values greater than 1,000 ppm (Table 3), compared to a median of 300 ppm barium for soils cited by Rose and others (1979). Residual concentrations in the soils would normally be expected, and the soil testing appears to have some potential as a barium reconnaissance tool.

Rock Samples

Rose and others (1979) listed the median barium values for limestone, sandstone, and shale as 92 ppm, 170 ppm, and 550 ppm, respectively. The limestone and graywacke samples examined were not enriched with respect to barium (Table 3). The black shales may show a slight enrichment of barium. Sample B-46-82 (Kurtz barn) was a composite of unmineralized black shale from a silo excavation near the barn. Black shale float was very difficult to obtain at the Gibble farm (B-42-82); thus the sample may not be representative of the mineralized area. No mineralization was megascopically visible in any of the black shale fragments examined. Samples pre-

Table 3. *Approximate Concentrations of Barium in Composite Stream-Sediment, Soil, and Rock Samples*

Location	Black shale		Limestone		Graywacke		Soil		Stream sediment	
	Sample no.	Approx. ppm	Sample no.	Approx. ppm	Sample no.	Approx. ppm	Sample no.	Approx. ppm	Sample no.	Approx. ppm
Bohn (40°25′45″N/76°17′12″W)	B-35-82	>1500	B-36-82	200						
Burkholder (40°26′54″N/76°17′02″W)	B-41-82	>1500	B-42-82	<100			S-4-82	1080	ST-5B-82	<100
Gibble (40°26′09″N/76°19′33″W)	B-42-82	920	B-43-82	<100			S-2-82	1340		
Huber (40°18′30″N/76°27′04″W)					B-53-82	<100				
Moore (40°26′22″N/76°18′56″W)					B-48-82	<100				
Kurtz barn (40°26′05″N/76°18′54″W)	B-46-82	550	B-45-82	<100						
Kurtz main show (40°26′06″N/76°19′01″W)	B-47-82	1280	B-26-82	<100			S-3-82	1150		
Kurtz/Landis (40°26′04″N/76°18′29″W)	B-51-82	1280	B-50-82	<100			S-1-82	1180	ST-1-82	<100
West end (40°26′38″N/76°19′51″W)									ST-3-82	<100
Middle portion (40°26′09″N/76°17′57″W)									ST-4-82	<100
East end (40°27′42″N/76°16′48″W)									ST-6-82	<100

sumed to be shale collected from two locations about 10 and 15 miles (16 and 24 km) west of the study area by Popper (1982) are not enriched with respect to barium.

Barite Concentrates

Barite concentrates from seven occurrences were scanned by X-ray fluorescence using a Cr tube at 50kV, 45mA, and LiF (200) analyzing crystal over the range from 5° to 50° 2θ. Strontium was the only element other than barium detected in significant amounts in these samples (B-19-82, B-25-82, B-27-82, B-34-82, B-41-82, B-44-82, and B-52-82).

Staining Techniques

An identification technique involving converting barite ($BaSO_4$) to witherite ($BaCO_3$) and staining this with a hot potassium chromate (K_2CrO_4) solution, as outlined by Carlson and others (1973), was attempted. The dark-gray color of the Berks County barite masks the bright yellow stain.

H_2S Test

Previous work by Smith (personal communication, 1983) suggests that there might not be any H_2S in the strongly fetid, coarsely crystalline barite. Fetid barite samples finely ground in a cadmium iodide solution did not yield any precipitates visible at 30X. He noted that the smell is like that of some mercaptans rather than H_2S. Miller and others (1977) found trapped fatty acids in black sedimentary barite from Arkansas and Nevada, which may account for the obnoxious odor.

GEOLOGIC ASSOCIATIONS OF KNOWN STRATA-BOUND DEPOSITS

Because this is the first substantial fetid barite reported in Pennsylvania, comparison with other developed or known strata-bound barite deposits is useful in evaluating the significance of these showings.[1]

Commercial deposits of generally fetid, dark-gray to black, fine-grained, bedded barite occur in Nevada, Arkansas, California, Alaska, northwestern Canada, West Germany, and India (Brobst, 1980). Common geologic associations of commercial bedded barite deposits, as outlined by Brobst (1980), are listed below:

(1) The host rocks are generally of early to mid-Paleozoic age. C. Stone (personal communication, 1983) reported that many Arkansas oc-

[1] Non-fetid, nodular barite containing sphalerite and pyrite from central Pennsylvania has recently been noted by Way and Smith (1983).

currences are early Mississippian, and K. Papke (personal communication, 1983) reported that Nevada occurrences are in rocks ranging in age from Cambrian through Devonian.

(2) Beds of dark barite are an inch (few centimeters) to more than 100 feet (30 m) thick.

(3) Laminated beds of fine-grained (less than 0.1 mm in diameter) barite are common; more massive beds occur in some places.

(4) Substantial parts of some barite beds are made up of nodules and rosettes.

(5) Nodular beds of barite may form envelopes around the higher grade beds of barite.

(6) Some barite nodules have concentric rings of barite.

(7) Barite rosettes have a radially bladed structure.

(8) Dark chert and siliceous siltstone and shale are commonly interbedded with barite.

(9) Many barite units contain 50 to 95 percent $BaSO_4$.

(10) The chief impurity is fine-grained quartz, and small amounts of clay and pyrite are common. Papke (personal communication, 1983) reported major quartz and mica, minor local calcite-dolomite, sparse pyrite, and rare clays for occurrences in Nevada.

(11) Carbonate minerals are uncommon.

(12) Beds of dark-colored barite contain several percent organic matter and characteristically give off an H_2S odor when struck.

Apparently, limestone is closely associated with some major strata-bound barite deposits, as reported by Mills and others (1971), Mitchell (1980), and Scull (1958). Lamey (1966) described Europe's most important barite deposit near Meggen, West Germany, as pyrite and barite replacing folded limestone of Devonian age. There is a gross similarity between Mitchell's (1980) stratigraphic section of the Miller mine in Nevada, which contains limestone, and the Berks County, Pennsylvania, showings, which also contain limestones (Figure 18).

A. V. Heyl (personal communication, 1982) pointed out the striking lithologic resemblance of the Martinsburg Formation (autochthonous) containing slate to the deposit hosts in Meggen and Rammelsburg, West Germany, where strata-bound sulfide and barite occur in folded limestone and slate of middle Devonian age.

CONCLUSIONS

1. Float of dark-gray, fetid, nodule-like barite fragments occurring in western Berks County, Pennsylvania, has characteristics commonly associated with commercial deposits developed elsewhere. These are: (a) the adjacent rocks are of Paleozoic age; (b) the barite is dark colored; (c) the barite crystals are radially bladed; (d) the barite is inter-

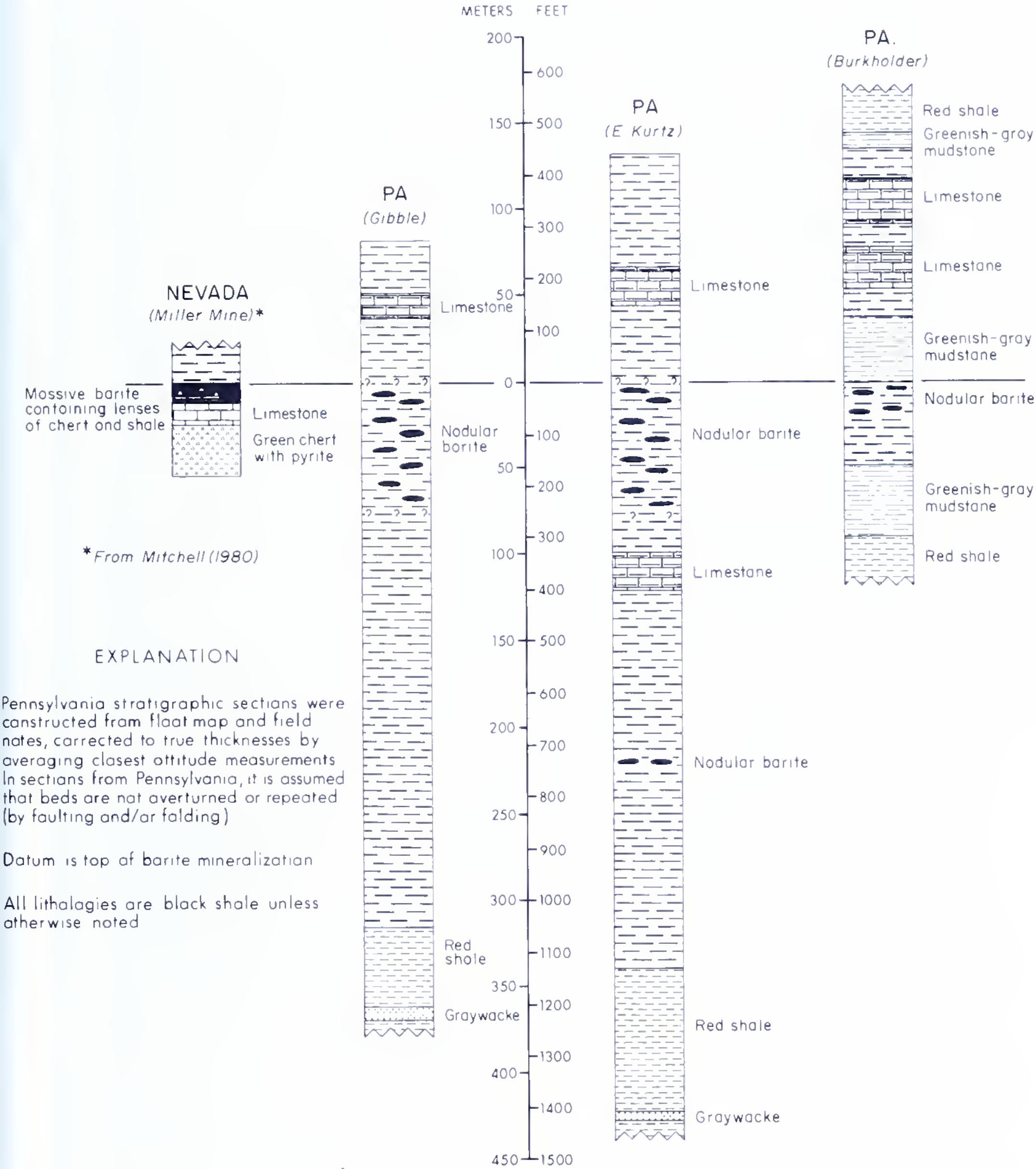


Figure 18. Generalized stratigraphic sections of significant mineralized areas in Pennsylvania compared to a generalized section of a commercial deposit in Nevada.

bedded or hosted by a dark shale; (e) the barite is relatively pure, and minor quartz and shale are the chief impurities; (f) the barite has a fetid odor when struck or scratched; (g) the barite is associated with organic matter; and (h) the barite could be interbedded with a dark chert.

2. The observed barite is confined to a black shale (dark-gray shale) host, which is part of a complex allochthonous group of mostly fine grained sediments of the Hamburg sequence of Cambro-Ordovician age.

3. Interpretations from the reconnaissance mapping of float suggest that the black shale is in east-west-trending units that are potentially large and continuous enough to contain minable ore-grade material. (A 1-million-ton deposit could have the following approximate dimensions: 30 feet (9 m) thick, continuous down dip for 150 feet (45 m), and a strike-length of 2,000 feet (600 m)). Apparent black shale sequences up to about 2,000 feet (600 m) thick may be present.
4. No concentrations of ore-grade material were observed at the 11 showings identified within the study area. However, the largest area of mineralization (300 by 350 feet, or 90 by 110 m) could be similar to the nodule-bearing beds reported forming envelopes around higher grade beds of barite in other districts. Down-dip intervals are untested for mineralization.
5. Barite mineralization in the black shales may continue outside the present study area to the southeast (Gordon, 1922; Genth, 1875). The allochthonous host rocks are thought to cover a belt approximately 80 miles (130 km) along strike and of varying thickness.
6. The ultimate source of barium is unknown. However, the described occurrences probably formed early in a black shale deposited in a reducing environment. Massive fine-grained barite suggesting sea-floor precipitation was not observed.
7. Most barite fragments have at least two crystal habits. A finer grained aggregate of subrounded crystals forming the core of a nodule probably grew first and represents faster crystal growth than the surrounding radially bladed crystals that form the remainder of the nodule. These nodules may have formed by early replacement of calcite(?).
8. No associated metals, except strontium, appear to be present with the barite.
9. Hydrocarbons, both a flammable gas and possible black bitumen, are associated with the barite.
10. Float mapping in black shale terrain, and perhaps the barium content of residual soils, could be used to define additional areas of near-surface mineralization within the allochthonous Hamburg sequence.
11. The color-alteration index (CAI) of conodonts from limestone blocks occurring in black shale sequences has been interpreted by Harris and others (1982) to have reached at least 180° to 220°C. Assuming an average geothermal gradient of about 30°C per kilometer, these rocks might have had a burial depth of about 7 km (4 mi).

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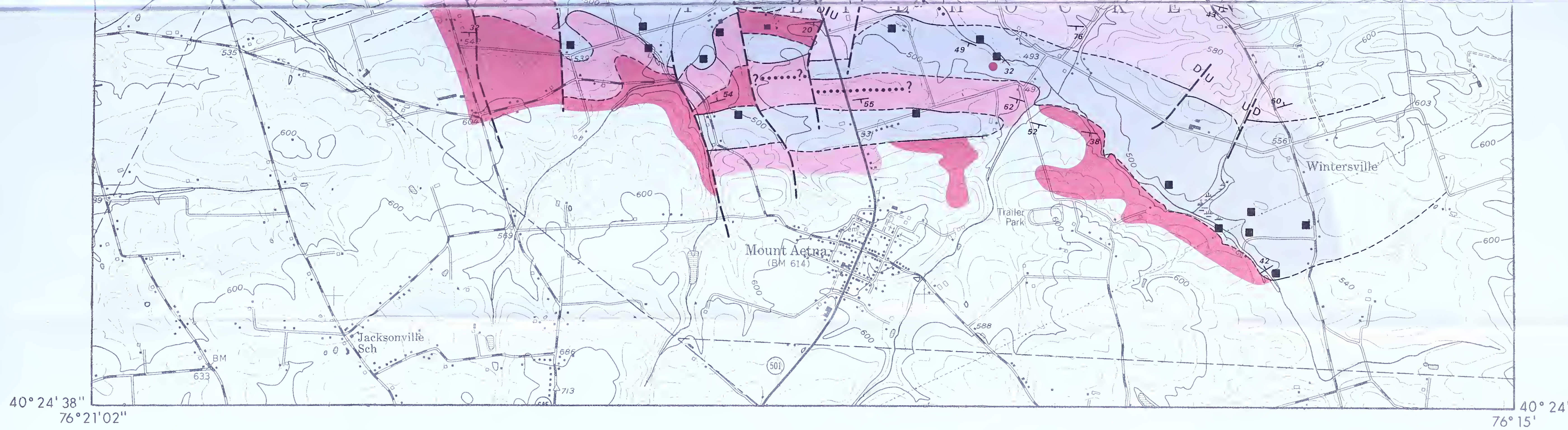


SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

N

Base map from U.S. Geological Survey 1:24,000 topographic map of Bethel quadrangle, 1974.

Geology based on field mapping (mainly observation of float) by S. W. Berkheiser, Jr., 1982.

EXPLANATION

SYMBOLS

- ■ Area of abundant limestone float; strike and dip symbol indicates outcrop
- ● Area of barite mineralization as delineated by float fragments
- ▲ Area of igneous-rock float
- .... Trace of possible graywacke bed
- 80 Strike and dip of possible bedding
- U D Fault; dashed where indefinite or inferred. U, upthrown side; D, downthrown side.
- Lithologic contact based on float association; dashed where indefinite or inferred

MAP PATTERN	PREDOMINANT FLOAT
	Red shale; minor orange shale, green shale, and graywacke
	Black shale; contains exotic limestone blocks
	Greenish-gray mudstone
	Orange shale and mudstone

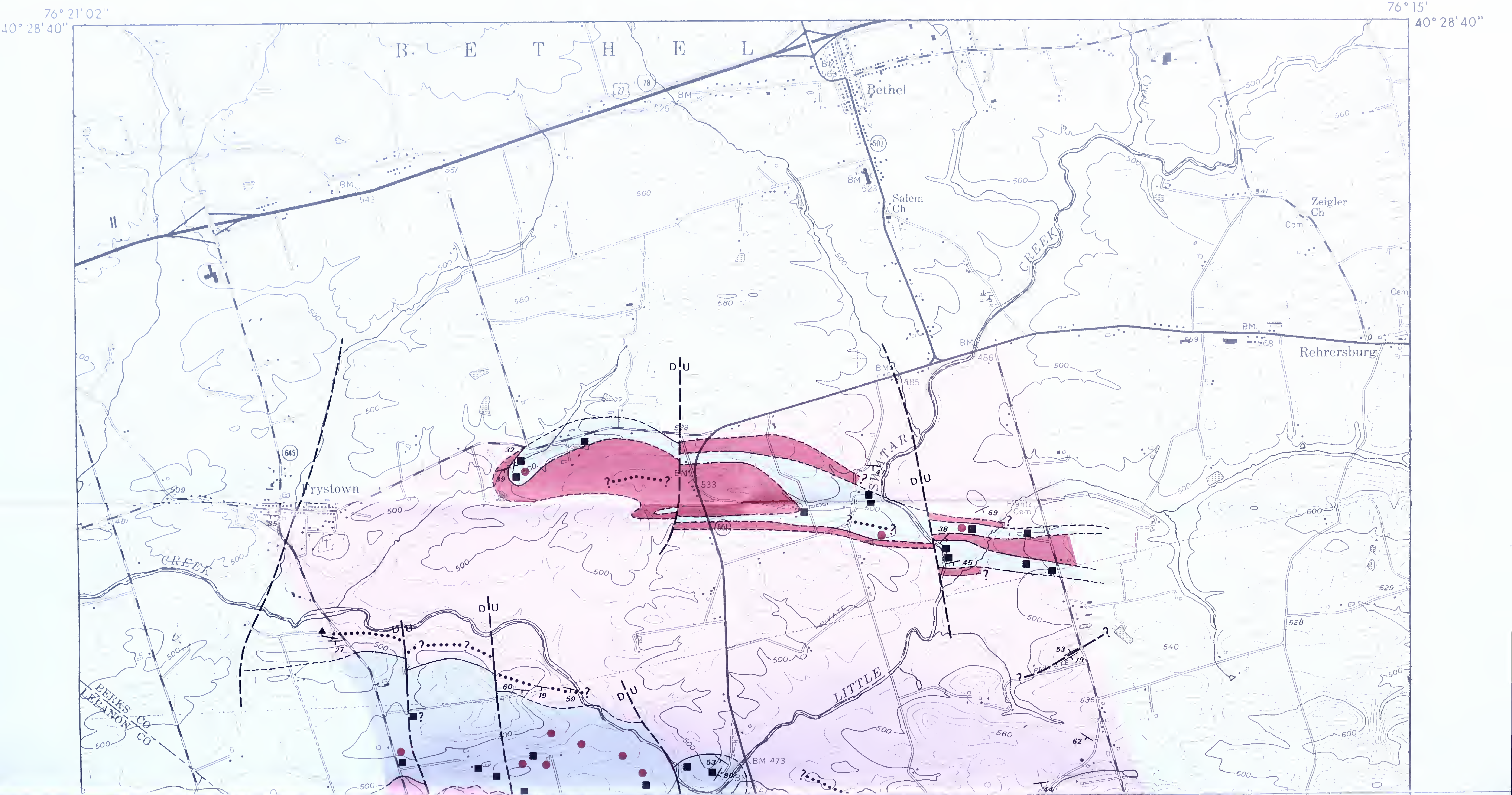
PLATE 1. GEOLOGIC MAP OF THE STUDY AREA

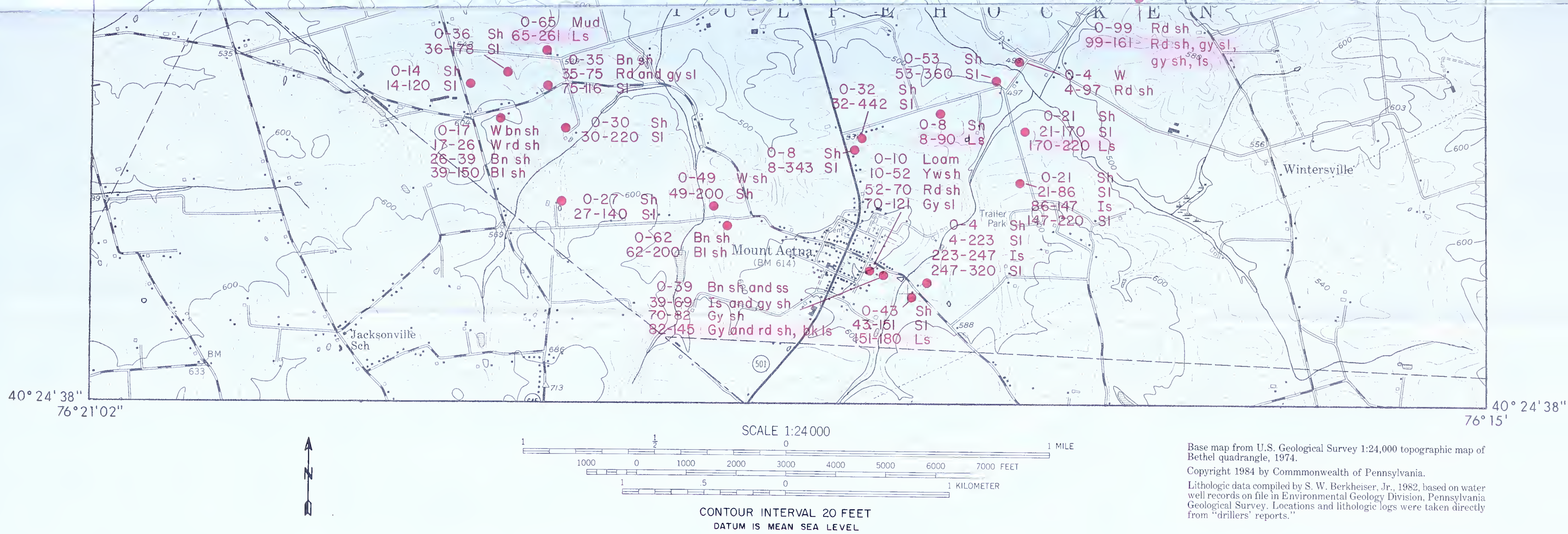
(Compiled mainly from observation of float)

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

M 84, Plate 1





Base map from U.S. Geological Survey 1:24,000 topographic map of Bethel quadrangle, 1974.

Lithologic data compiled by S. W. Berkheiser, Jr., 1982, based on water well records on file in Environmental Geology Division, Pennsylvania Geological Survey. Locations and lithologic logs were taken directly from "drillers' reports."

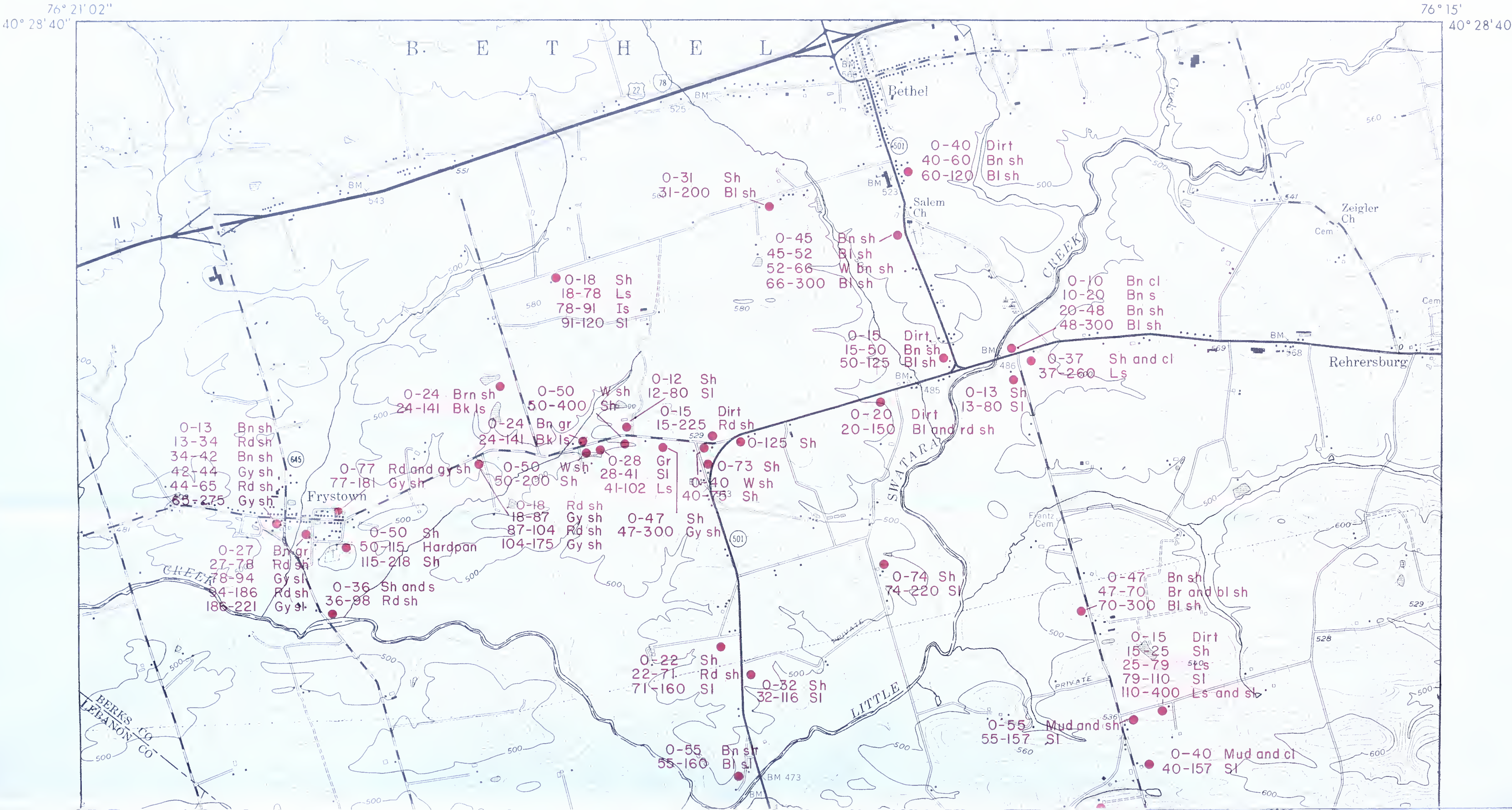
EXPLANATION

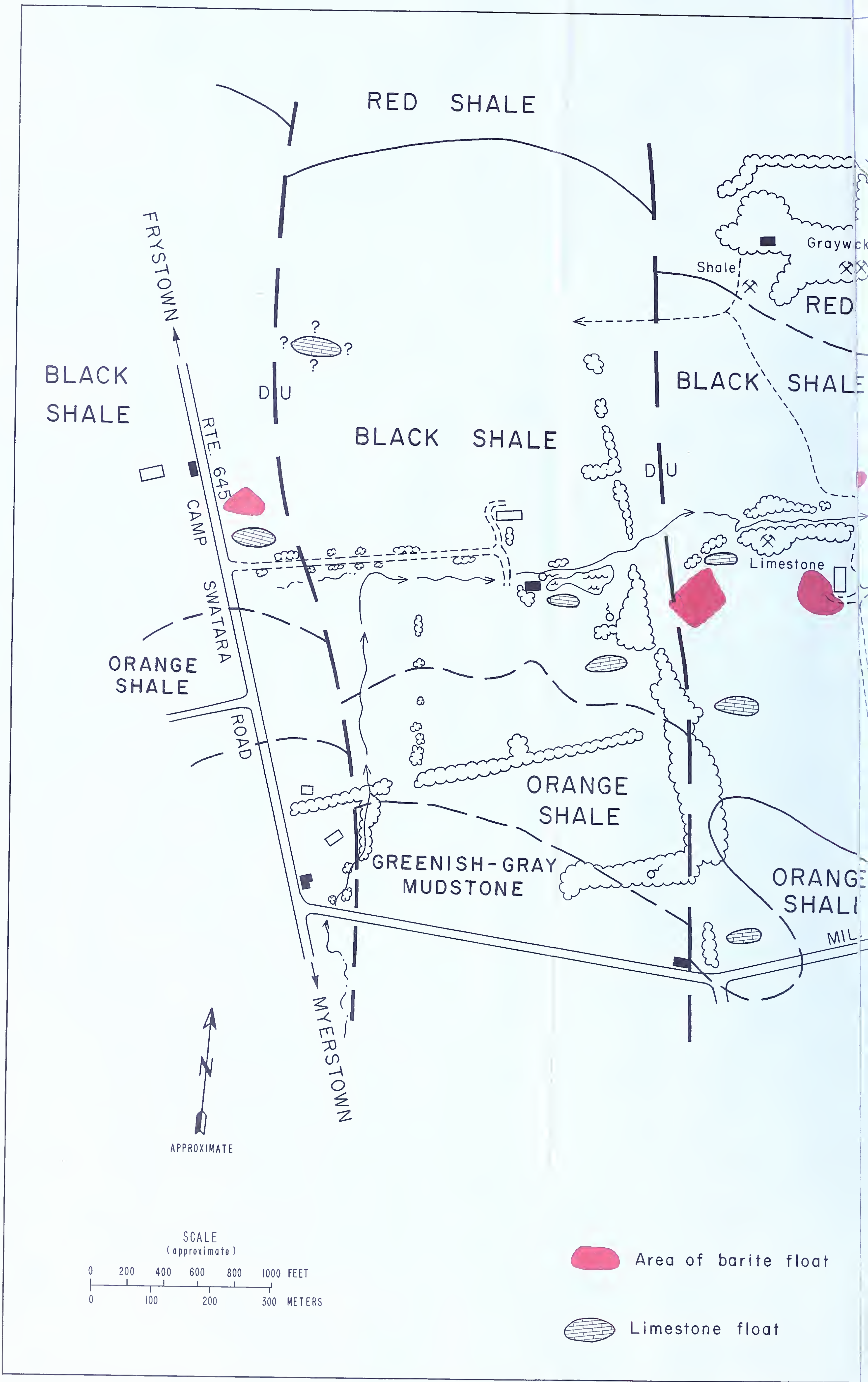
W	Weathered	Ls	Limestone	S	Sand	Bn	Brown	Gn	Green	Bk	Black
Sh	Shale	Is	Ironstone	Cl	Clay	Rd	Red	Yw	Yellow		
Sl	Slate	Gr	Gravel	Ss	Sandstone	Gy	Gray	Bl	Blue		

Interval containing potential barite host rock in the subsurface

PLATE 2. LITHOLOGIC DATA FOR THE STUDY AREA

(Compiled from water well records on file in the Environmental Geology Division, Pennsylvania Geological Survey. Locations and lithologic logs are directly from "drillers' reports.")

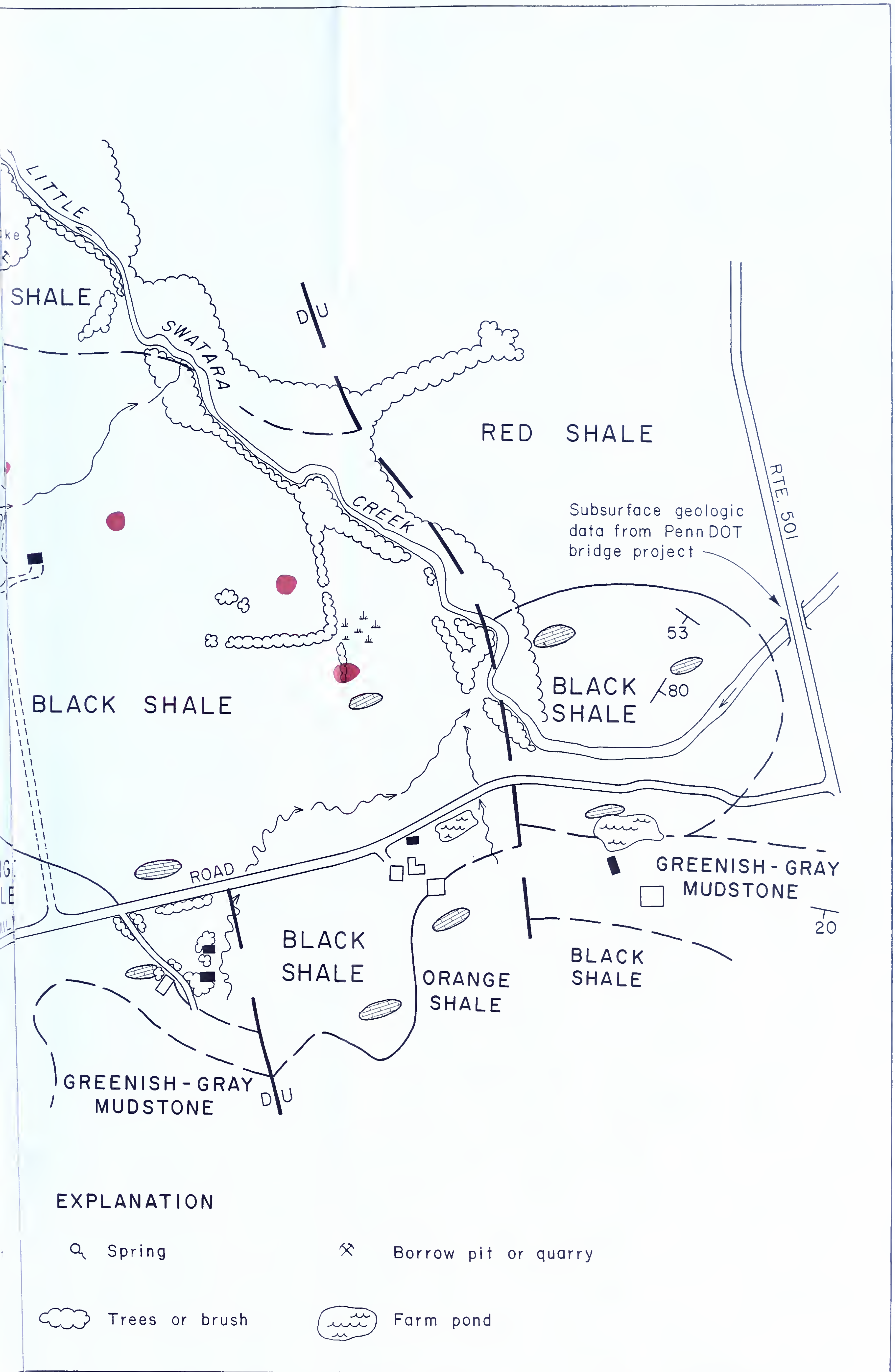

76° 21' 02"
40° 28' 40"
76° 15'
40° 28' 40"
B E T H E L
Bethel
Salem Ch
Zeigler Ch
Rehrersburg
Frystown
SWATARA
LITTLE
CREEK
BERKS CO
LEBANON CO
0-40 Dirt
40-60 Bn sh
60-120 Bl sh
0-31 Sh
31-200 Bl sh
0-45 Bn sh
45-52 Bl sh
52-66 W Bn sh
66-300 Bl sh
0-18 Sh
18-78 Ls
78-91 ls
91-120 Sl
0-10 Bn cl
10-20 Bn s
20-48 Bn sh
48-300 Bl sh
0-15 Dirt
15-50 Bn sh
50-125 Bl sh
0-37 Sh and cl
37-260 Ls
0-13 Sh
13-80 Sl
0-20 Dirt
20-150 Bl and rd sh
0-24 Brn sh
24-141 Bk ls
0-50 W sh
50-400 Sh
0-12 Sh
12-80 Sl
0-15 Dirt
15-225 Rd sh
0-24 Bn gr
24-141 Bk ls
0-125 Sh
0-13 Bn sh
13-34 Rd sh
34-42 Bn sh
42-44 Gy sh
44-65 Rd sh
65-275 Gy sh
0-77 Rd and gy sh
77-181 Gy sh
0-50 W sh
50-200 Sh
0-28 Gr
28-41 Sl
41-102 Ls
0-73 Sh
0-40 W sh
40-753 Sh
0-18 Rd sh
18-87 Gy sh
87-104 Rd sh
104-175 Gy sh
0-47 Sh
47-300 Gy sh
0-50 Sh
50-115 Hardpan
115-218 Sh
0-27 Bn gr
27-78 Rd sh
78-94 Gy sl
94-186 Rd sh
186-221 Gy sl
0-36 Sh and s
36-98 Rd sh
0-74 Sh
74-220 Sl
0-47 Bn sh
47-70 Br and bl sh
70-300 Bl sh
0-15 Dirt
15-25 Sh
25-79 Ls
79-110 Sl
110-400 Ls and sh
0-22 Sh
22-71 Rd sh
71-160 Sl
0-32 Sh
32-116 Sl
0-55 Mud and sh
55-157 Sl
0-55 Bn sh
55-160 Bl sl
0-40 Mud and cl
40-157 Sl



Base map is an enlarged sketch from Soil Conservation Service aerial photograph AHJ-1MM-38, July 8, 1971.

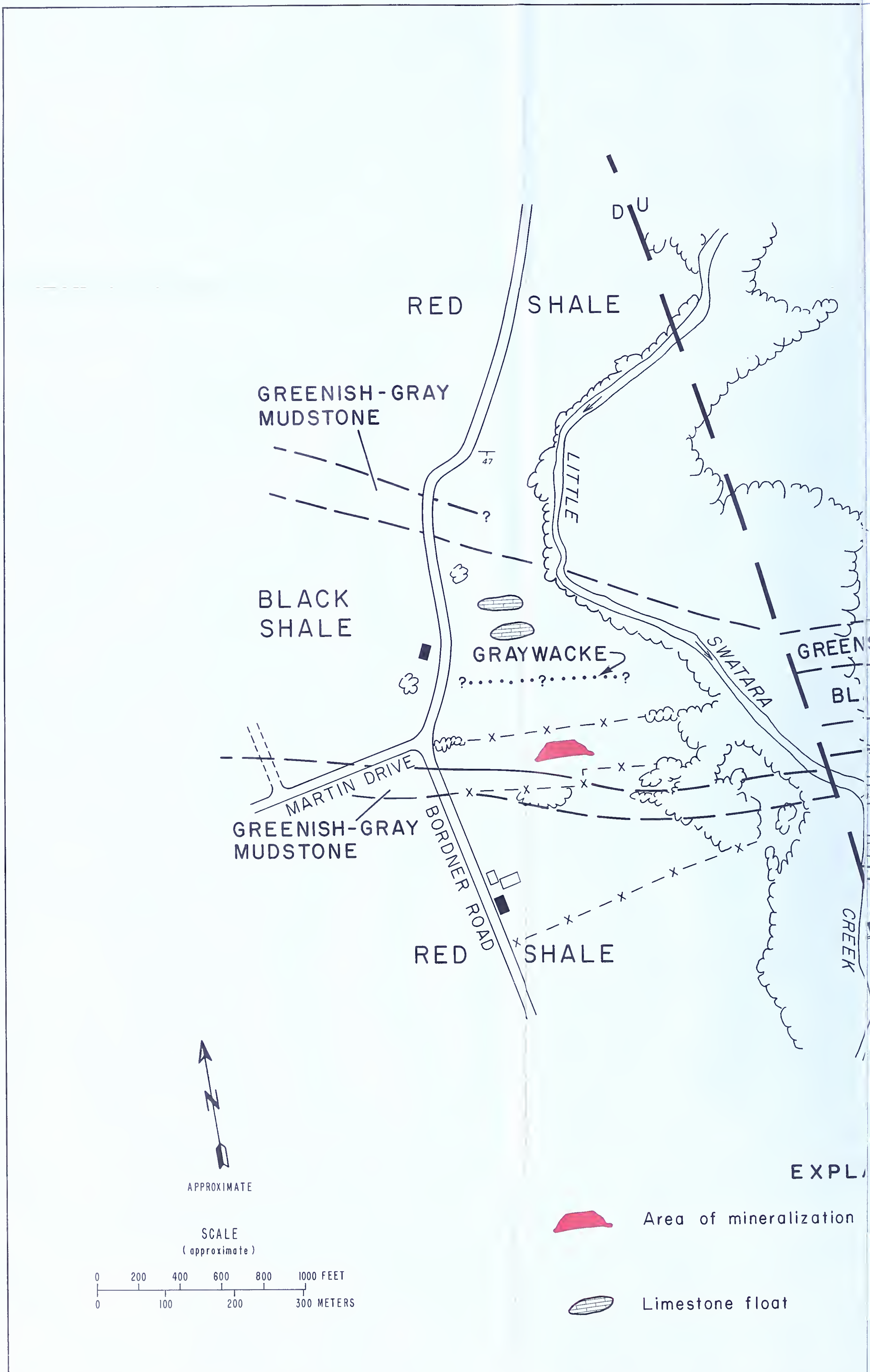
PLATE 3. DETAILED MA[P ...] MINERALIZATION OBSERV[ED ...] SHALE SEQUENCE, BER[KS ...]

(Gibble, E. Kurtz, an[d ...]



Geology by S. W. Berkheiser, Jr., 1982, based on field observations, including pace-and-compass traverses.

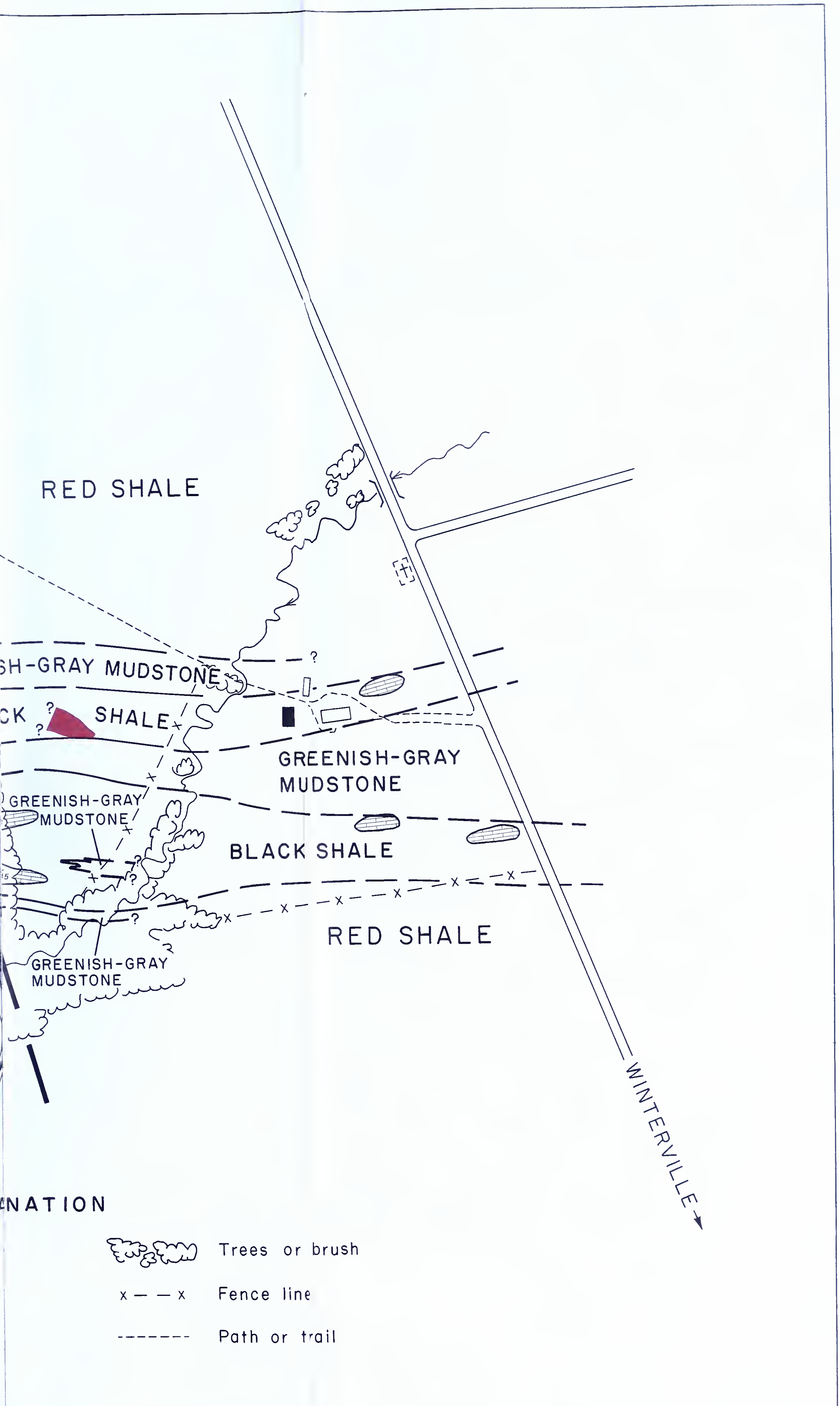
OF SIGNIFICANT BARITE
D IN THE SOUTHERN BLACK
S COUNTY, PENNSYLVANIA
L. Kurtz/Landis showings)



Base map is an enlarged sketch from Soil Conservation Service aerial photograph AHJ-1MM-55, July 8, 1971.

PLATE 4. DETAILED MAP
MINERALIZATION OBSERVE
SHALE SEQUENCE, BERKS

(Sadler and Burl



Geology by S. W. Berkheiser, Jr., 1982, based on field observations, including pace-and-compass traverses.

OF SIGNIFICANT BARITE IN THE NORTHERN BLACK COUNTY, PENNSYLVANIA

older showings)